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JOINT COMMITTEE PRINT

**BIOLOGICAL AND ENVIRONMENTAL
EFFECTS OF NUCLEAR WAR**

SUMMARY-ANALYSIS OF HEARINGS
JUNE 22-26, 1959

JOINT COMMITTEE ON ATOMIC ENERGY
CONGRESS OF THE UNITED STATES



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ERRATUM

On page 8, beginning at the 12th line from the bottom, the paragraph should read:

“Probably the most significant finding presented to the subcommittee was that civil defense preparedness could reduce the fatalities of the assumed attack on the United States from approximately 25 percent of the population to about 3 percent. The provision of shielding against radiation effects would at the same time protect against blast and thermal effects for the vast majority of the population.”

SUMMARY-ANALYSIS OF HEARINGS ON BIOLOGICAL AND ENVIRONMENTAL EFFECTS OF NUCLEAR WAR

I. INTRODUCTION

For the first time in history American communities have become a part of the main battlefield of a possible future war. Only on few occasions in the past have American homes and civilians been endangered by armed conflict, and never has there been a threat of wholesale destruction and loss of life such as that now posed by a powerful and ruthless adversary armed with nuclear weapons. The subcommittee believes that the American people, whose homes and lives are now threatened, have a right to know the basic facts of nuclear warfare within the bounds of security restrictions.

Beginning on June 22, 1959, the Special Subcommittee on Radiation held 5 days of public hearings on the biological and environmental effects of a possible nuclear war. The subcommittee's purpose was to establish a public record clearly setting forth the scientific facts concerning the probable physical and biological effects of such a war on man and his environment. To the subcommittee's knowledge, this is the first time any comprehensive presentation of such facts has been made to the American people or to the people of any other nation.

The scope of these hearings did not include consideration of the overall impact of nuclear war upon the Nation's economy, specific recovery measures, or the problem of industrial recuperation in the long-range postattack situation. Nor did the subcommittee consider the controversial question of governmental or individual responsibility for financing a national civil defense system.

At the outset the subcommittee wishes to note also that these hearings were not designed to determine the exact form of a possible future nuclear war or the likelihood that such a war will occur. Nor does this report contain any such predictions or conclusions.

It is believed that the data presented in these hearings and summarized in this report will enable the American public to understand more clearly the basic scientific facts of a possible nuclear war and to achieve a better appreciation of the fundamental issues of our national security program.

In the course of the hearings the importance of understanding the facts of a possible nuclear war was underscored and reemphasized by numerous expert witnesses. Simply to understand that "unprecedented destruction" is *not* the same as "unlimited destruction"—as one witness pointed out—is crucial to intelligent discussion of the issues.

At the same time, no one appearing before the subcommittee attempted to minimize or make light of the terrible destructiveness of nuclear weapons. Rather, every effort was made to achieve an ob-

jective appraisal of weapon effects through a step-by-step examination of the problems by competent witnesses based on quantitative computations.

Although the testimony emphasized many of the uncertainties of nuclear war, it was noted that the relevance of quantitative estimates today is most impressive. It was pointed out that modern science makes possible greater accuracy in predicting what a nuclear war would be like.

Moreover, quantitative estimates make possible more precise thought and more accurate communication in a subject field fraught with misconceptions and emotional, moral and spiritual issues. Although such estimates when presented in an objective manner, may erroneously imply a disregard for, or callousness toward, moral and spiritual values, they are nevertheless essential to an objective consideration of the basic facts. It is fully recognized that facts about nuclear carnage are not pleasant. It is without precedent that a committee of the Congress analyzes casualties on the scale encountered in nuclear war. But the subcommittee had no choice but to face up to these grim facts.

The subcommittee believes that the fundamental issues dealt with in these hearings are extremely serious, and that they are issues which need to be understood, considered and discussed. As stated by one witness:

If you are afraid to discuss the issue, you will certainly be afraid to meet the crisis if and when it occurs.

It was apparent from the hearings held by this subcommittee in 1957,¹ that there is a very large practical difference between the problem created by the world-wide fallout coming from a program of testing nuclear weapons, and those that would result from the use of these weapons in an all-out war. Accordingly, the fallout problems associated with the testing of nuclear weapons were considered in a separate hearing² early in May of this year, with the problems of nuclear war being investigated in the June hearings.

The contrast between the two types of problems may be illustrated by a few examples. All the test programs of the U.S.S.R., Great Britain, and the United States to date have involved the detonation of approximately 170 megatons of total yield, of which about 90 megatons have been fission yield. These test detonations have occurred over a 10-year period at different latitudes and under varying climatic conditions and have consisted of surface bursts, tower bursts, under-water bursts, and air bursts at high and low altitudes.

The problems considered in the June 1959 hearings involve the hypothetical detonation of approximately 4,000 megatons total yield, of which approximately 2,000 megatons constitute fission yield, all consisting of surface detonations occurring within a period of 1 day. This was accepted as a realistic possibility should a nuclear war come.

The test programs to date have been conducted at remote places—in Australia, at isolated Pacific islands, in Nevada,³ and inside the Soviet Union. Therefore, we have been primarily concerned with

¹ Hearings on the "Nature of Radioactive Fallout and Its Effects on Man," May 27-29, and June 3-7 1957.

² "Fallout From Nuclear Weapons Tests," hearings held by the Joint Committee on Atomic Energy, May 5, 6, 7, and 8, 1959.

³ Kiloton size only.

material drawn into the troposphere and stratosphere and the subsequent worldwide deposition of the radioactive debris.⁴ In the June hearings we were concerned with hypothetical detonations in the midst of cities and military bases. Consequently, it was necessary to consider the far more severe immediate and local effects—blast, thermal and radiation—which, under conditions of the test programs, to date, would not be encountered normally.

The biological effects of the radioactive fallout resulting from the test programs to date are so slight that they must be evaluated on the basis of an estimated increase in the incidence of naturally occurring effects, such as leukemia on the one hand or inherited effects such as abnormalities or stillbirths. Under conditions of nuclear war, we are concerned with problems of immediate survival of the millions of people who may be subjected to radiation exposures as severe as or greater than those received by a few individuals accidentally exposed to momentary but high intensity radiation in Government research operations.

In order to consider the problems of a possible nuclear war, the subcommittee prepared a hypothetical attack situation in which nuclear weapons of varying sizes were placed on specific targets within the United States. In addition, a specific total weapons contribution was arbitrarily assigned to other areas of the Northern Hemisphere to take into consideration also the worldwide fallout resulting both from a hypothetical retaliatory attack by the United States and from an enemy strike against U.S. overseas bases.

Having established this basic framework, the subcommittee then prepared a topical agenda and invited a distinguished and competent group of experts, to present testimony on the probable biological and environmental effects of such an attack on the United States.

No classified information was used in developing the subcommittee's hypothetical attack assumptions, and to insure against the possibility of any direct or indirect inferences to existing classified war plans or weapons stockpile information, the subcommittee refrained from requesting the support of any Department of Defense agency in establishing the attack pattern.

The attack situation, including the sizes of weapons and their distribution on specific targets, was carefully developed by the subcommittee and represents assumptions considered realistic. However, the subcommittee has no wish that the assumed attack be taken as representing anything more than a hypothetical example. Other attack patterns of greater or lesser total megatonnage could have been planned and, by the same token, extrapolations from this specific pattern (and effects) can be made upward or downward. The purpose of the subcommittee's particular attack assumptions was to set forth a uniform basis and framework for analysis by the various individuals asked to testify or submit statements for the subcommittee record.

The Office of Civil and Defense Mobilization cooperated to the fullest extent in depicting the subcommittee's attack assumptions on maps, charts, and other visual aids and in computing structural damage and human casualties on the basis of the subcommittee assumptions.

⁴ It should be noted, however, that the May hearings were also concerned with phenomena related to local "hot spots" resulting from radioactive contributions to the atmosphere by the test programs.

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The resources of the Atomic Energy Commission, its personnel and unclassified publications, were made available by Chairman McCone and were of great value to the subcommittee.

The subcommittee also utilized a mass of unclassified data furnished by other governmental and private sources on the effects of radiation. A special mention of appreciation is due Dr. Paul Tompkins and his associates of the U.S. Naval Radiological Defense Laboratory. Much of the basic data presented at the hearings was derived from the work of the USNRDL, and Dr. Tompkins and his staff consulted freely with the subcommittee throughout the hearings and during the preparation of this report.

The witnesses presenting testimony were selected on the basis of their competence and experience in the different fields of nuclear phenomena, with particular emphasis on nuclear weapons effects.

In the biomedical field the subcommittee received testimony from those scientists and technical personnel having the broadest experience in laboratory work on test animals and in the treatment of human beings exposed to radiation at Hiroshima and Nagasaki and in the accidental contamination of the Marshall Islands.

For the consideration of structural damage from blast and fire and of other weapons effects, outstanding authorities presented their findings and the latest available scientific data.

The weather patterns and other meteorological data for the date of the hypothetical attack were established by experts of the U.S. Weather Bureau, supported by their worldwide organization.

The reader is encouraged to examine the full testimony and supporting data of each witness in the printed record of the hearings. In this report the subcommittee has endeavored to present a faithful and concise summary of the data and to highlight the key issues for the convenience of the public and the Congress. Naturally, these data and issues are more completely set forth in the verbatim hearing record.

II. SUMMARY

THE HYPOTHETICAL ATTACK

The hypothetical attack set forth by the subcommittee assumed that 263 nuclear weapons in 1, 2, 3, 8, and 10 megaton sizes with a total yield of 1,446 megatons⁶ were detonated on 224 targets within the United States. An additional 2,500 megatons were assumed to have been detonated elsewhere in the Northern Hemisphere in attacks on overseas U.S. bases and in retaliation against the aggressor homeland. All weapons were arbitrarily designated as having a yield of 50 percent fission and 50 percent fusion. A weapon with 50 percent fission yield is one in which 50 percent of the total energy (yield) is derived from the fission process. Nuclear fission refers to the splitting of heavy atoms such as uranium and is the primary source of contamination of radioactive fallout particles.

⁶ A 1-megaton bomb has the same explosive energy release as 1 million tons of TNT. The Hiroshima bomb yield was estimated at 20,000 tons of TNT, or 20 kilotons.

CASUALTIES AND DAMAGE TO DWELLINGS

The expert testimony and supporting scientific data presented at the subcommittee hearings indicate that under present conditions such an attack would have cost the lives of approximately 50 million Americans, with some 20 million others sustaining serious injuries. More than one-fourth (11.8 million) of the dwellings in the United States would have been destroyed and nearly 10 million others would have been damaged. Some 13 million additional homes would have been severely contaminated by radioactive fallout. Altogether, approximately 50 percent of existing dwellings in the United States would have been destroyed or rendered unuseable for a period of several months.

Although the weapon detonations used in this exercise were designated as surface bursts, which would maximize the local radioactive fallout hazard, nearly 75 percent of the deaths would have resulted from the blast and thermal effects, combined with immediate radiation effects. Only 25 percent of all fatalities would have resulted from fallout. At the same time, more than half of the surviving injured would have radiation injuries.

Most of the damage sustained by dwellings would have resulted from the blast and thermal effects.

BIOLOGICAL EFFECTS

The three casualty-producing phenomena of nuclear weapons—blast, thermal, and radiation—occur in varying combinations, depending on proximity to the point of detonation. At close range one would encounter all three, including fallout radiation as well as immediate radiation from the fireball.

1. Blast effects

Blast produces primary effects resulting from the blast wave itself (lung damage, rupture of eardrums); secondary effects, resulting from flying fragments (loose debris, building materials) propelled with great force by the blast wave; and tertiary effects, resulting from the body itself being thrown violently by the blast wave. In addition, miscellaneous injuries will result from conditions created by the blast on surrounding objects (e.g., broken gas mains, downed power lines).

Approximately 95 percent of the blast casualties produced by a 10-megaton weapon will result from the secondary and tertiary blast effects. For this size weapon the secondary effects are important to a distance of 11 miles; the tertiary effects can occur to distances of from 7 to 16 miles.

2. Thermal effects

Thermal effects consist of fires caused by direct ignition of combustible materials, skin burns on exposed portions of the body, and temporary or permanent blindness from the intense light of the fireball.

In the hypothetical attack situation posed by the subcommittee, thermal effects, including the hazard of mass fires ("fire storms"), could extend over large areas, in some cases up to distances of 20 to 25 miles from the point of detonation.

3. Radiation effects

The most severe form of radiation injury, under conditions of nuclear war, would be that resulting from severe exposure to the primary radiation "flash" (close to ground zero) or that attending whole body exposure to close-in fallout during the first day or so. However, severe irradiation could occur as a result of prolonged exposure to local fallout even after the first day unless survivors were provided with adequate shelter protection. Direct contamination of the skin with fallout debris could produce painful "beta burns" due to the action of beta rays irradiating the skin and outer layers of the body surface. In addition, there is an internal hazard of radioactive material which gains entry into the body through inhalation, ingestion, or through open wounds.

(1) *Acute effects.*—Instantaneous radiation doses of 5,000 roentgens or greater immediately produce symptoms of shock; death occurs within hours.

Radiation doses of 1,000 to 5,000 roentgens produce nausea and vomiting, fever and general fatigue within a few hours. Temporary recovery is followed within 1 or 2 weeks by reappearance of symptoms and probable death.

Exposure to doses of 200 to 1,000 roentgens causes nausea and vomiting within a few hours and in the period of from 2 to 4 weeks after exposure major changes will occur in the composition of the blood, rendering the body particularly susceptible to infections during this time. Approximately one-half of those exposed at the level of 450 to 700 roentgens would be expected to recover if not subjected to additional physical stress or radiation. The other one-half would die within 2 to 4 months. Probability of recovery increases greatly at levels below 450 roentgens.

Radiation doses of 200 roentgens or less will produce only mild symptoms of nausea and vomiting. Changes in the blood may occur later, but individuals so exposed usually will not require hospitalization.

(2) *Effects of protracted radiation.*—Higher radiation doses can be tolerated by the body without developing symptoms of acute radiation illness if exposure is spread over a longer period of time. Approximately 90 percent biological recovery can occur with continued or repeated exposures, but the remaining 10 percent nonrepairable injury may produce late effects, such as cancer, over a period 20 years or more.

When only a part of the body is exposed, the ability to recover is greatly increased. For example, the exposure of a person's legs alone to 500 roentgens of radiation would not result in a lethal dose.

The probability of increasing the incidence of leukemia and other types of cancer is considered proportional to the average total radiation dose sustained by the surviving population. Potential deaths from this cause are estimated as about 2 percent of the deaths attributable to acute radiation injury. These deaths will be spread out over a period of decades since it is a characteristic of radiation-induced cancer to be long delayed after incidence of injury.

(3) *Skin burns from fallout.*—Skin burns can be caused by beta rays from the fallout particles coming in direct contact with the skin. However, very large doses of beta radiation are required to produce severe burns, and the particles may be removed from the skin by good

personal hygiene. Though less a threat to survival than whole body gamma radiation, beta burns can create open lesions which are easily infected.

(4) *Inhalation and ingestion hazards from fallout.*—Limited data suggest that inhalation (through breathing) and ingestion (through eating and drinking) of radioactive materials would in general constitute a relatively small hazard in comparison with total body radiation from the fallout field itself. The testimony indicated that this type of exposure would not become a major threat to survival in the immediate postwar period.

(5) *Genetic effects.*—The study of genetic effects of massive radiation on man is very limited. There is considerable evidence that the radiation exposure of a nuclear war would greatly increase genetic mutations for some succeeding generations. However, the widespread argument that the ultimate genetic consequences could lead to the virtual elimination of the human race is not supported by the testimony. The consensus of expert testimony was that the race could and would survive the type of hypothetical attack considered in these hearings, notwithstanding the inevitable costs in physical impairments and deaths due to additional genetic mutations.

ENVIRONMENTAL CONTAMINATION

A subject of major importance to the surviving population of a possible nuclear war is the consequences of introducing large quantities of radioactive materials into the environment. Three main categories of effects were considered with respect to environmental contamination: effects on animals, effects on food supplies, and long-term effects.

1. *Effects on animals*

It is quite probable that very large numbers of animals used as a source of food would be killed by exposure to fallout. Many mammals have an LD-50^{5a} in the range of 500–1,000 roentgens and since they would be provided with little shelter, fallout would be expected to exact a heavy toll. However, surviving animals might well serve as a source of food, freer from radioactivity than other foods, if the flesh is eaten and certain organs and milk are discarded or used only as animal food.

Although some animals may incur increased incidences of disease due to lowered body resistance, radiation doses in the lethal range are necessary to impair fertility. The deleterious effects of genetic mutations in these animals could be ameliorated by the practice of selective breeding.

2. *Effects on food supplies*

Food crops already harvested and not destroyed by blast and thermal effects may become contaminated by local fallout. However, the radioactive particles can normally be removed.

The principal barrier to the recovery of growing food crops would be the shortage of fuel and machinery, together with the radiation hazard to workers.

In general, if the external gamma radiation level permits the growing, harvesting, and processing of foods, the corresponding threat of radioactivity in this food when consumed would not impair survival and recovery from the attack. However, in zones of heavy local

^{5a} Lethal dose for 50 percent of those exposed. Cf. pp. 13-14.

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fallout decontamination would be required to reduce the strontium 90 content of the soil to a level acceptable for production of some food crops and milk.

3. *Long-term environmental effects*

Although much remains to be learned about the long-range impact of a nuclear war on "the balance of nature," the consensus of the testimony was that, despite the severe shock, life would continue and full ecological recovery would eventually occur.

ADDITIONAL DATA ON RADIOACTIVE FALLOUT

Several additional factors presented to the subcommittee with respect to radioactive fallout are considered highly important.

(1) The worldwide strontium 90 fallout resulting from the assumed attack would not pose a major survival problem in countries not attacked. The level of strontium 90 deposited from long-term fallout would be higher than the maximum permissible concentration recommended for the population as a whole on a peacetime standard, but lower than the recommended maximum permissible occupational dose under controlled conditions.

(2) The actual release of gamma radiation energy from fission products differs significantly from that represented by the standard formula ($t^{-1.2}$ rule) contained in the official Government publication, "The Effects of Nuclear Weapons." New calculations indicate that early dose rates will be of greater intensity than previously believed and that over a long period of time the rate of decline will be more rapid. While the problem of immediate survival in a nuclear war is thus increased, the problem of long-term recovery is reduced.

(3) Local fallout is significantly affected by wind and weather. Actual fallout contours will differ markedly from the idealized cigar-shaped patterns normally used as a basis of estimating fallout effects. Moreover, peak fallout intensities will almost never occur at or near the point of weapon detonation. For example, the maximum fallout intensity for a weapon of a 5- to 10-megaton yield may appear at a distance as great as 60 to 70 miles from the point of detonation.

SURVIVAL MEASURES

Probably the most significant finding presented to the subcommittee was that civil defense preparedness could reduce the casualties of the assumed attack on the United States from approximately 30 percent of the population to about 3 percent. The provision of shielding against radiation effects would at the same time protect against blast and thermal effects for the vast majority of the population.

The cost of providing high-performance shelter protection for 200 million people was estimated at between \$5 billion and \$20 billion.

The main conclusion presented to the subcommittee was that the country must have a national radiological defense system if the Nation is to withstand and recover from an attack of the scale which is possible in an all-out nuclear war.

STRATEGIC IMPLICATIONS

In the course of the hearings the subcommittee received testimony on some of the strategic implications of the scientific data presented. A digest of this testimony and related panel commentary is included in an addendum to the report.

III. THE ATTACK PATTERN AND BASIC ASSUMPTIONS

The attack pattern and basic assumptions established by the subcommittee for consideration in these hearings reflected an attack against the United States on a limited scale. That is, the number and total megatonnage of weapons employed were less than the maximum which a potential enemy is capable of launching against the United States.

At the same time, the pattern of the hypothetical attack was designed for a greater dispersion of weapons than would obtain in a so-called "limited" attack directed only against U.S. strategic offensive forces.

Although no classified information was utilized and the attack pattern was developed without assistance from any governmental agency, the realism of the assumptions was confirmed at the request of the subcommittee by competent military experts.

The targets in the United States were selected on the basis of criteria used by the Office of Civil and Defense Mobilization in its unclassified civil defense exercises and from published lists of military bases and Atomic Energy Commission installations.

The hypothetical attack consisted of 263 nuclear weapons delivered on 224 targets in the United States. The total megatonnage (millions of tons of TNT explosive equivalent) of the attack was 1,446, consisting of weapons ranging in size from 1 megaton to 10 megatons, as indicated in the following table:

TABLE III—1.—*Weight of the attack*

Size of weapon	Number used	Weight of attack (megatons)
10 megatons.....	60	600
8 megatons.....	74	592
3 megatons.....	44	132
2 megatons.....	37	74
1 megaton.....	48	48
Total.....	263	1,446

Of the 224 targets, 71 were large industrial and population centers officially designated by the OCDM as "Critical Target Areas." Military installations constituted an additional 132 targets and the remaining 21 targets were Atomic Energy Commission facilities.

The following table indicates the dispersion of weapons among the several classes of targets:

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TABLE III—2.—*Targets of the attack*

Type of target	Number	Number of weapons	Weight (megatons)
Air Force installations.....	111	111	645
Critical target areas.....	71	110	567
AEC installations.....	21	21	168
Army installations.....	12	12	24
Navy installations.....	5	5	28
Marine Corps installations.....	4	4	14
Total.....	224	263	1,446

All weapons were arbitrarily designated as 50 percent fission and 50 percent fusion weapons detonated at ground level, that is, with the fireball touching the earth's surface. Each weapon was assumed to have been detonated at or near its specified target by using a standard statistical method for random bombing errors.

The total of 1,446 megatons was considered the yield of the weapons detonated, not the gross attack which the aggressor force might have launched initially, and no attempt was made to "war game" the overall problem of weapon delivery, interception, and retaliation.

For purposes of computing worldwide fallout and its effects for a period of 5 years after the attack, again without war gaming, it was assumed that 2,500 megatons of weapons were detonated on areas of the Northern Hemisphere outside the continental United States, representing the net result of attacks on U.S. overseas bases and U.S. retaliatory strikes against the aggressor homeland.

The general distribution of targets in the United States is illustrated on the map in figure III—1.

The time of the hypothetical attack was set at 12 noon Greenwich time (7 a.m. eastern standard time) on a typical October day, which assumes completed harvest and storage of food crops in the aggressor homeland. The actual weather conditions used in plotting fallout patterns and determining the effects of meteorological factors were those recorded for October 17, 1958, a typical fall day. It was necessary to select a particular day in the past in order to provide the weather data for accurate calculations.

IV. BASIC EFFECTS OF WEAPONS EMPLOYED

As indicated above, the weapons employed in the hypothetical attack assumptions consisted of 50 percent fission and 50 percent fusion weapons ranging in size from 1 to 10 megatons, all detonated at ground level. The following data concerning the basic effects of these weapons were presented at the subcommittee hearings. Later sections of this report will discuss the biological and environmental effects of these weapons in greater detail.

1. *Partition of energy in a nuclear explosion*

About 35 percent of the total energy of a nuclear explosion is given off as radiant thermal energy or heat, in much the same way as the sun radiates heat. Another 50 percent of the bomb energy is contained in the blast wave that travels several times the speed of sound. About

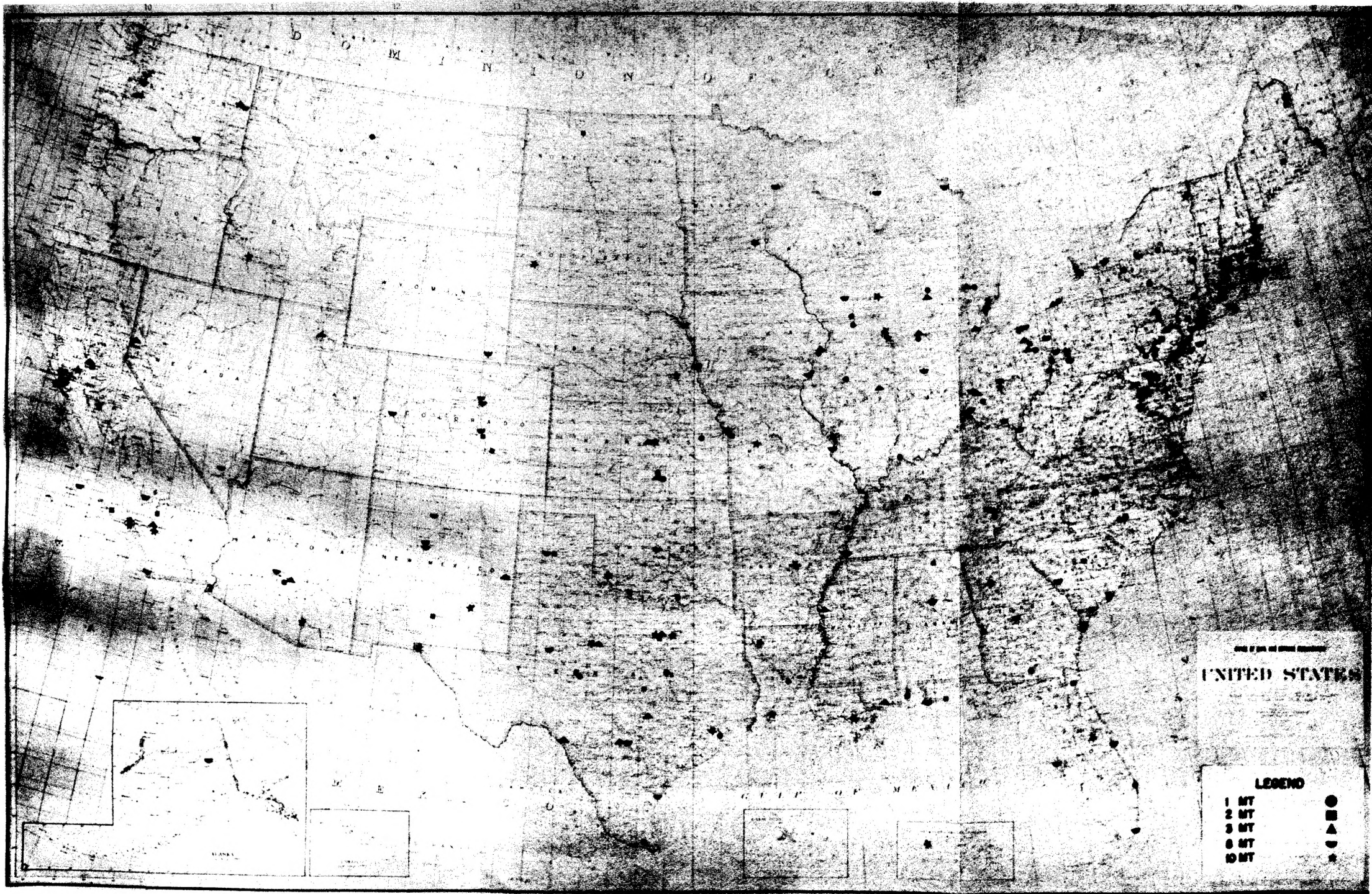


FIGURE III-1

5 percent of the total energy is given off directly from the exploding bomb as prompt nuclear radiation in the form of gamma rays, neutrons and other particles such as alpha and beta. The remaining 10 percent of the total energy is released from the radioactive-fission products over long periods of time.

In the case of a large yield surface burst, such as the 10-megaton weapon used in the subcommittee's assumption, approximately 80 percent⁶ of the fission products fall back to the ground to form the local fallout pattern. About 15 percent of the fission products from a surface burst remain high in the atmosphere (stratosphere) for very long periods of time (half residence time the order of a year or more)⁷ and return to the earth's surface as worldwide contamination. Approximately 5 percent would be worldwide tropospheric (lower atmosphere) fallout in a band near in latitude to the point of detonation.

2. Differences in airbursts and surface bursts

Airburst.—An airburst is one in which the fireball does not come in contact with the ground. (See fig. IV—1.) In a large-yield airburst nearly all of the fission products are deposited in the stratosphere, thus making a maximum contribution to the worldwide fallout with essentially no local fallout. The blast wave is reflected and reinforced at the earth's surface. In general, the range of thermal and nuclear radiation received by ground targets will be greater than for a surface burst.

FIGURE IV—1



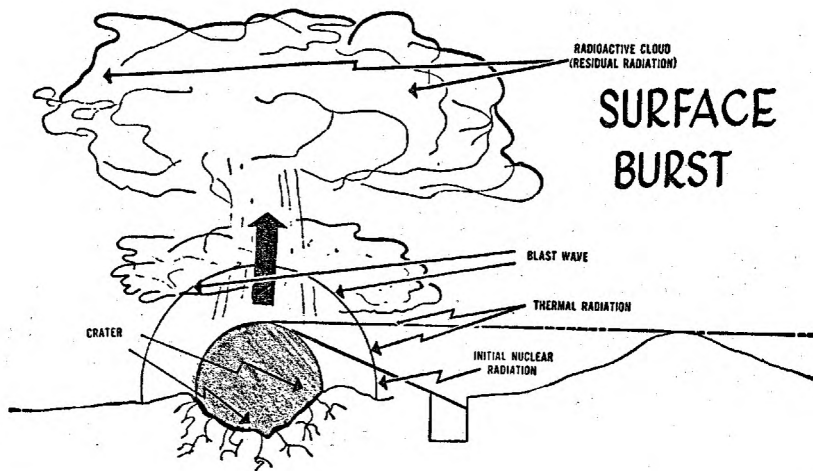
⁶ The figure of 80 percent may be too high. Actually, there is very little experimental data on the percentage of fallout coming down locally for surface-burst megaton weapons. The 80 percent figure might well be 50 percent under some circumstances.

⁷ The mean residence time is the half residence time divided by 0.7. The half residence time is the time required for the amount of material in the stratosphere to be reduced by 50 percent. These concepts are analogous to the mean life for radioactive decay.

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Surface burst.—A surface burst is one in which the fireball intersects the surface. (See fig. IV-2.) Local fallout is maximized in a surface burst. A crater is formed in the vicinity of the burst and is highly radioactive. The range of thermal and nuclear radiation effects is reduced by the natural shielding of hills and buildings.

FIGURE IV-2



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43. Nuclear weapons effects on materials and structures

(1) **Blast.**—Multistory brick apartment houses are quite vulnerable to the blast wave. All such structures would be destroyed within a radius of 7 miles from ground zero for a 10-megaton weapon and within 3 miles for a 1-megaton burst. Thus, a factor of 10 in yield changes the radius of destruction by about a factor of 2.

A well-constructed wood-frame house completely collapses within 9 miles from a 10-megaton surface burst and within 4 miles of a 1-megaton burst.

(2) **Thermal.**—Fires can be started by the ignition of light kindling materials anywhere within about 9 miles from a 1-megaton burst and within 25 miles from a 10-megaton burst. Thus, the presence of light kindling materials, such as trash, paper, and unpainted wood in a residential area will probably result in widespread fires.

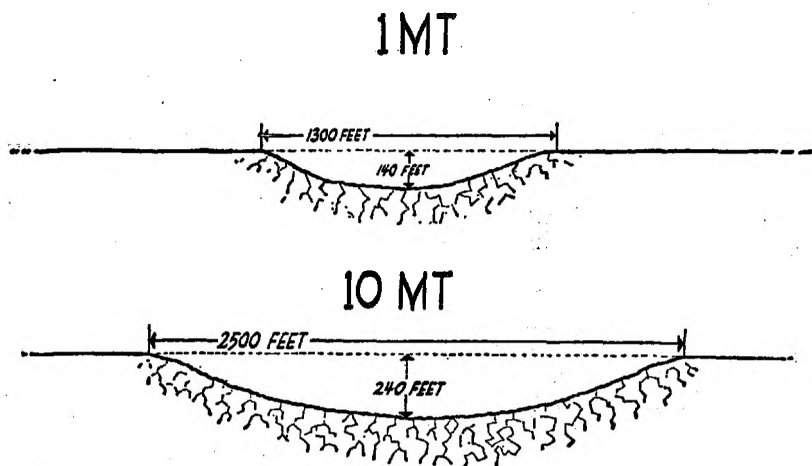
(3) **Nuclear radiation.**—Initial nuclear radiation and fallout have very little effect on most inanimate materials. However, fallout can deny the use of inanimate objects to man until they are decontaminated by removing the radioactive particles.

(4) **Crater.**—Such hard structures as underground installations are quite invulnerable to the other effects, but can be destroyed by the cratering effect of a surface burst. (See fig. IV-3.) The damage would not be confined to just the crater dimensions, but would extend also into the rupture zone, a region having a diameter about twice the

crater diameter. Almost no structure nor its occupants would survive within this region.

FIGURE IV-3

CRATERING IN DRY SOIL



4. Nuclear weapons effects on man

(1) *Blast.*—Blast overpressure in itself is not a significant casualty agent. However, the secondary effects and injury caused by crumbling buildings, flying debris, and man himself being thrown about, are certainly significant. Extensive blast injury can be expected at distances at which brick apartment houses collapse (7 miles from 10 megatons and 3 miles from 1 megaton). Extensive window breakage and flying glass would also occur at these and somewhat greater distances.

(2) *Thermal.*—Second degree burns of the hands or face will incapacitate an individual. For a 1-megaton burst, an exposed person 9 miles from ground zero on a clear day can be expected to receive second degree burns on the exposed skin. For a 10-megaton burst, this range would be less than three times as great, or about 25 miles.

(3) *Initial radiation.*—Nuclear radiation is measured in units of rem (roentgen equivalent mammal). A rem is defined as the amount of radiation of any type required to produce a biological effect equivalent to that of 1 roentgen of X-ray. Two hundred rem will cause vomiting and nausea in 50 percent of a group of people by the end of the first day, but none or very few would be expected to die. A dose of 450 rem would cause vomiting and nausea in all of a group by the end of the first day, and according to the official handbook entitled "The Effects of Nuclear Weapons,"³ about half of the people so exposed would be expected to die within 30 days. This is termed the

³"The Effects of Nuclear Weapons," prepared by the U.S. Department of Defense and published by the U.S. Atomic Energy Commission, Washington: U.S. Government Printing Office, 1957.

"lethal dose 50 for 30 days" (LD 50). However, data suggesting higher dose rates for 50 percent were presented to the subcommittee and are discussed later in this report, beginning on page 37. When exposed to 600 rem the entire group would become sick within 4 hours and a very large percentage of them would soon die. With a dose of 1,000 rem, all would be incapacitated within 1 to 2 hours, and all would die very soon thereafter.

Nuclear radiation emitted directly from the exploding bomb within the first minute would be at least 700 rem within a range of 1.5 miles from a 1-megaton burst and within 2 miles from a 10-megaton burst. This is a prompt dose of radiation that certainly means death to the unshielded or unsheltered in this region. It is, however, a region for large-yield surface bursts where blast and thermal effects are also extremely hazardous or lethal to the unsheltered population.

(4) *Local fallout*.—Due to the assumption that all the weapons used in the Subcommittee's exercise are detonated at ground level, that is, with the fireball touching the surface of the earth, maximum local fallout would result.

Generally stated, in a surface burst, large quantities of earth are drawn into the fireball and become mixed with the fission products of the weapon. This mixture of earth and fission products is carried to high altitudes by a rising column of heated air. Upon cooling, this material gradually falls back to the earth. These particles, contaminated with radioactive products, are the fallout.

Local fallout is that which comes down in the general region of the earth in which the detonation occurred, that is, within several hundred miles, at most, and within a few days.

The local fallout pattern is usually irregular in shape but having the general outline of a long cigar with one end at the burst point. For a 10-megaton surface burst with 50 percent of its yield due to fission, there would be an area of about 2,500 square miles (extending about 150 miles downwind and having a maximum width of about 25 miles) within which all people exposed in the open without shelters would obtain a dose of at least 450 rem during the first 48 hours. The dose of 450 rem would occur on the edge of the fallout pattern. Inside of the 2,500 square miles the fallout radiation and doses would be greater near the center of the fallout pattern and at distances closer than 150 miles downwind from the burst. The fallout radiation would be less outside of the 2,500 square miles area at distances greater than 150 miles downwind or away from the center of the fallout pattern. Inside of the above fallout pattern for a single weapon there are areas with radiation intensities as high as 3,000 roentgens per hour up to 1 hour after the detonation.

(5) *Worldwide fallout*.—Worldwide fallout is produced by the fine particles which ascend high into the troposphere and stratosphere, are carried by the winds around the earth, and descend over a long period of time. Tropospheric fallout descends within about 1 month in a more or less banded region of the same general latitude of the detonation. Stratospheric fallout is more delayed, occurring within a few months to a few years.

Approximately 20 percent of the total fallout of the weapons used in the subcommittee's exercise would be of the worldwide type. Fifteen percent would be stratospheric and about 5 percent would be tropospheric.

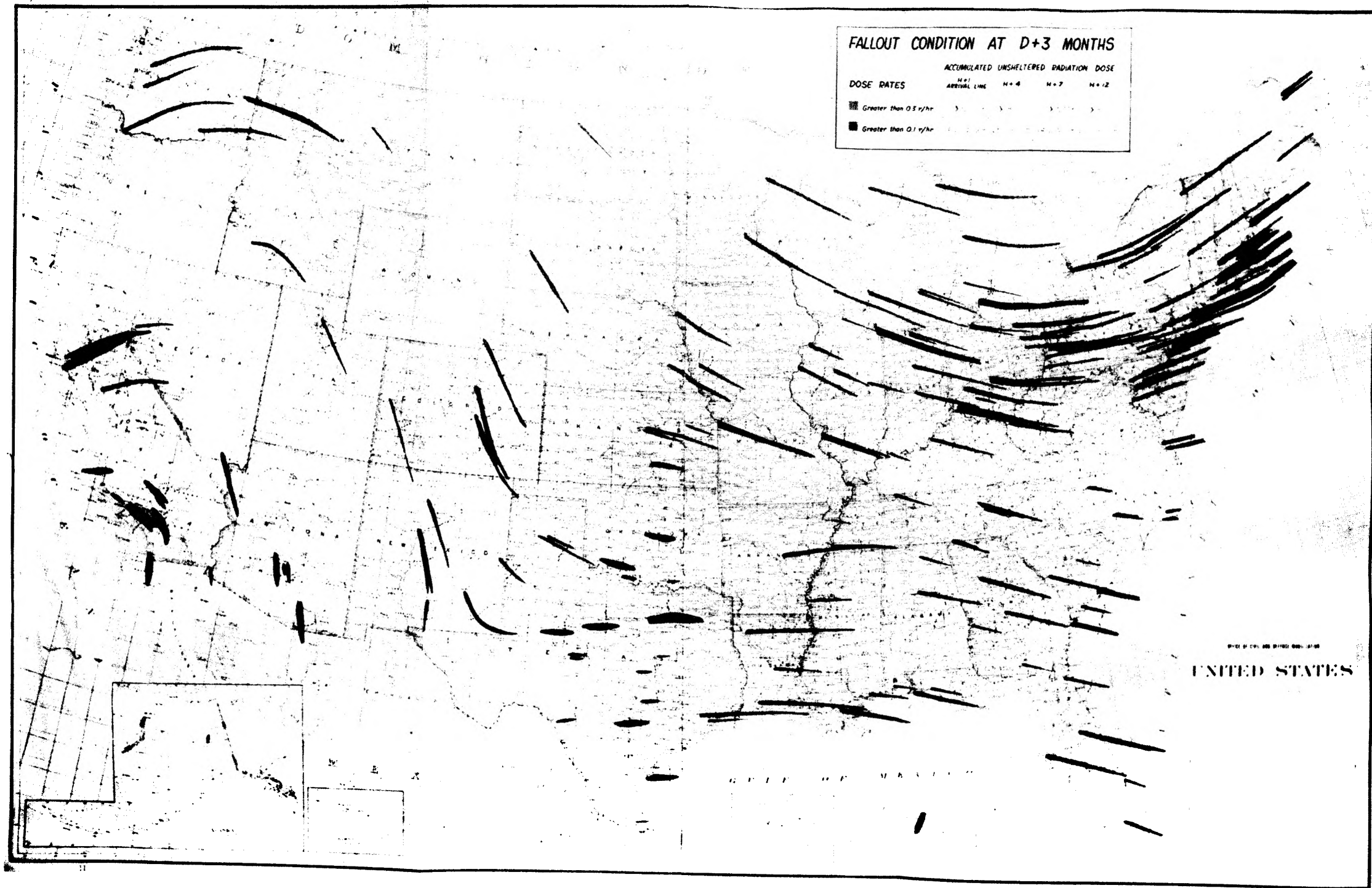


FIGURE V-5

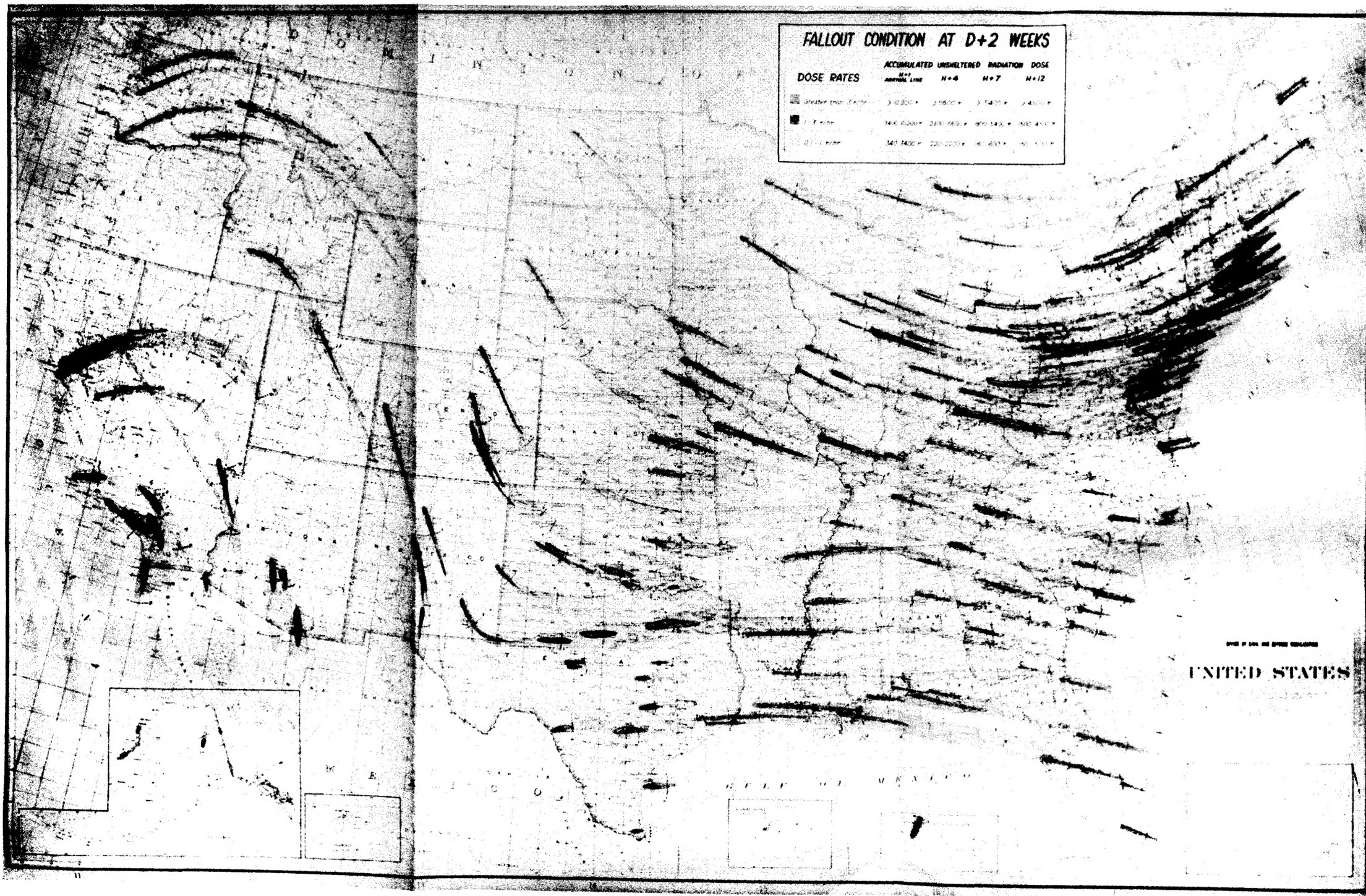


FIGURE V-4

FALLOUT CONDITION AT D+2 DAYS

DOSE RATES

ACCUMULATED UNSHELTERED RADIATION DOSE

	H=4	H=7	H=12
Greater than 30 r/hr	8100 r	4500 r	3300 r
10-30 r/hr	2700-8100 r	1500-4500 r	1100-3300 r
1-10 r/hr	270-2700 r	150-1500 r	110-1100 r
0.1-1 r/hr	27-270 r	15-150 r	11-110 r

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UNITED STATES

FIGURE V-3

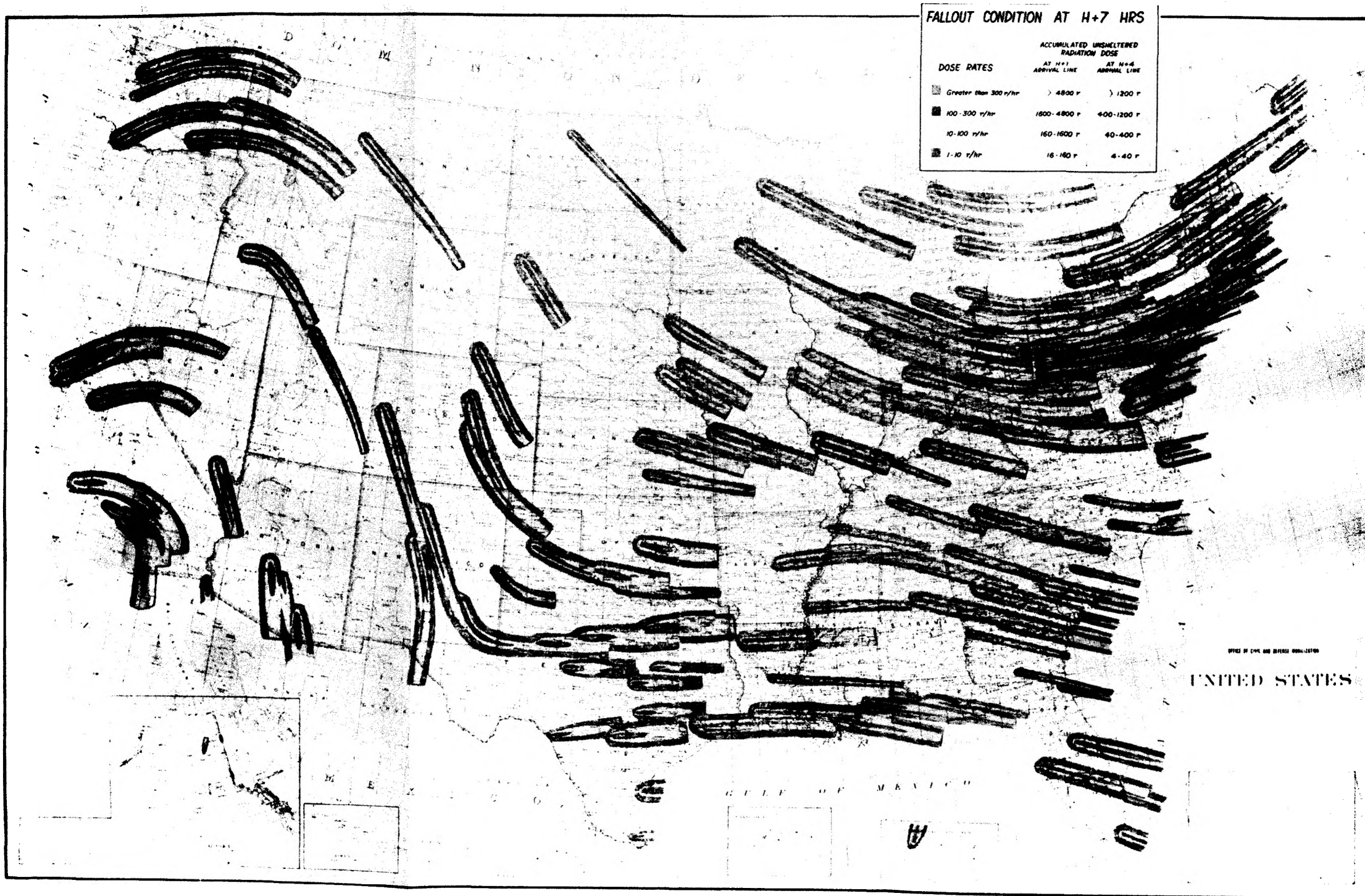


FIGURE V-2

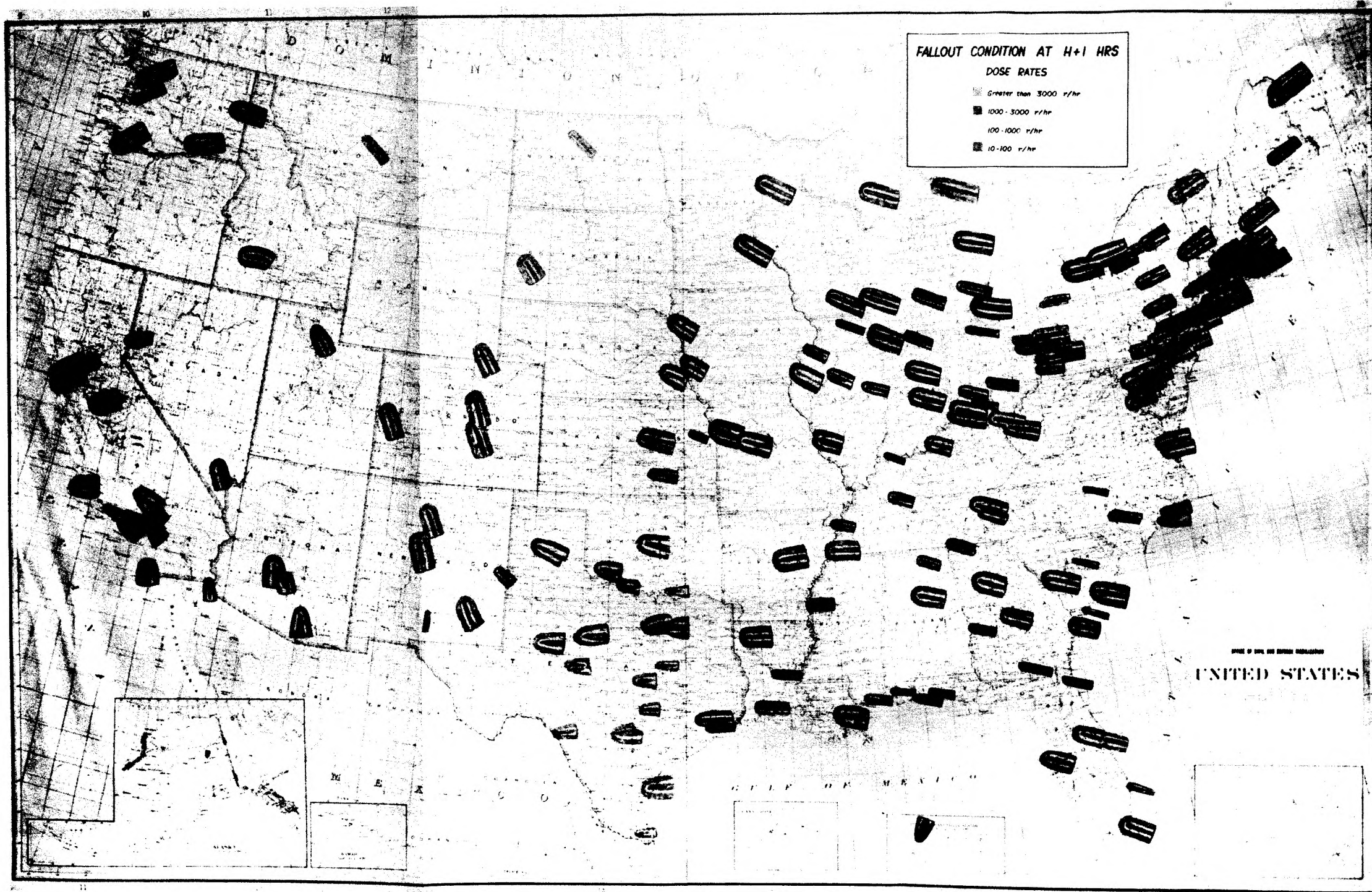


FIGURE V-1

approximately 30 percent of the national land area is covered by fallout intensities exceeding 1 roentgen per hour; and after 2 days 46 percent of the national land area is affected by intensities ranging from one-tenth roentgen per hour to greater than 30 roentgens per hour. Two weeks after the attack, as a result of radiation decay, only 15 percent of the national land area has fallout intensities exceeding one-tenth roentgen per hour and after 3 months only 5.8 percent of the area is affected by this intensity.

Two important factors concerning these fallout data require special attention. First, it is important to distinguish between the radiation dose rates, indicated here, and total dose accumulation, that is, the total dose which an unsheltered person would receive in a given period of time at a specified geographic location. Secondly, the stated dose rates as computed by OCDM are based on the $t^{-1.2}$ decay principle, which is at variance with later findings of the U.S. Naval Radiological Defense Laboratory.

The $t^{-1.2}$ rule, which long has been accepted by the scientific community, simply means that in general the radiation intensity existing 1 hour after a nuclear explosion will decline by a factor of 10 for every sevenfold increase in time. That is, if the 1-hour postattack dose rate is 3,000 roentgens per hour, 7 hours after the explosion the rate will be 300 roentgens per hour. Forty-nine (7×7) hours after the explosion the rate will be 30 roentgens per hour. At 343 ($7 \times 7 \times 7$) hours after the explosion the rate will be 3 roentgens per hour.

Although the NRDL data suggest a slower initial decline in dose rate, they indicate a more rapid decline after 1 year. However, whether one uses the $t^{-1.2}$ rule or the NRDL data, the requirement for population shielding in the period immediately following a possible attack remains substantially the same. A fuller discussion of the NRDL data is contained in a later section of this report, beginning at p. 28.

With respect to total radiation doses, data presented at the hearings indicate that in some sections of the country the hypothetical attack would have produced accumulated doses exceeding 12,000 roentgens during the first 3 months. As pointed out by OCDM witnesses, this means that persons who survived the initial impact of the attack in such highly contaminated areas would have to be moved to safer locations.

It should be noted that the official OCDM position with respect to the radiation hazards of a possible nuclear war is that fallout shelters should be prepared for the entire population of the United States. Although the fallout projections in figures V-1, 2, 3, 4, and 5 show some areas of the country to be free of fallout and others to be contaminated with extremely low radiation intensities, such areas cannot be accurately predicted in advance of a possible attack because of variables in such factors as target selection, aiming errors, weapon sizes and weather conditions.

DAMAGE SUSTAINED BY DWELLINGS

The blast damage sustained by dwellings in the United States as a result of the hypothetical attack is indicated in table V-1. Eleven million eight hundred thousand dwellings, or more than one-fourth of

the dwellings in the United States, suffered damage to the extent that they would not be salvageable.

An additional 8.1 million dwellings suffered moderate damage and would have to be evacuated for major repairs; and 1.5 million dwellings suffered light damage. This totaled 21.4 million dwellings damaged.

TABLE V-1.—*Effects on dwelling*

	<i>Units</i>
Blast effects:	
Severe damage.....	11, 800, 000
Moderate damage.....	8, 100, 000
Light damage.....	1, 500, 000
Fallout effects:	
Greater than—	
3,000 roentgens per hour.....	500, 000
1,000 to 3,000 roentgens per hour.....	2, 100, 000
100 to 1,000 roentgens per hour.....	10, 400, 000
Less than 100 roentgens per hour.....	11, 700, 000

Outside the areas of blast and thermal damage, some 2,600,000 dwellings sustained radiation intensities exceeding 1,000 roentgens per hour and would have to be evacuated and abandoned for periods extending up to several months. An additional 10.4 million dwellings sustained radiation intensities varying between 100 and 1,000 roentgens per hour. With major decontamination effort most of these 10.4 million homes could be recovered by 60 days postattack.

In summary, almost 50 percent of existing dwellings in the United States were either severely damaged or contaminated by fallout to the extent that they would not be usable for at least several months postattack.

CASUALTIES

Based on 1950 census data, it was calculated that 19.7 million persons would have been killed the first day; 22.2 million additional persons would have been so badly injured that they would subsequently die of their injuries. There would have been approximately 17.2 million additional persons injured who could be expected to recover from the injuries received. Of those killed, 25 percent would have died from fallout and approximately 75 percent would have died as a result of blast and thermal injuries, combined to a great extent with radiation injuries.

Of the surviving injured, approximately 6.3 million would have blast and thermal injuries and 10.9 million would have radiation injuries.

Due to the population increase of approximately one-sixth since the 1950 census, it was noted that these casualty estimates might be increased by approximately 16 percent on a national basis. If this increase is included, the above casualty estimates would be changed to 22.8 million persons killed on the first day; 25.7 million additional persons fatally injured; and 19.9 million persons nonfatally injured. This increase, however, cannot be accurately applied to individual area estimates.

The charts which follow (tables V-2 and 3), again based on 1950 census data, show the numbers of fatalities and surviving injured by OCDM regional areas, by States, and within the 71 population and industrial centers included as targets in the hypothetical attack. It will be noted that of the total 19.7 million people killed on the first day, approximately 11.4 million were in the 12 largest metropolitan areas

in the United States. The New York City area sustained the greatest loss with over 6 million dead or dying and over 2 million surviving injured. Seventy-five percent of the persons living in the Boston area were killed, and in Los Angeles fatalities amounted to 65 percent. In Chicago fatalities amounted to only 18 percent of the population, while in Baltimore they approached 80 percent.

With respect to radiation casualties, it is important to note that the OCDM estimates assumed that the population would take advantage of the fallout protection provided by existing buildings. The protection factors used in these estimates ranged from a reduction to one-half for those afforded the worst protection to a reduction to one two-hundredth for those afforded the best protection. It is possible that some groups of the population would have less protection than one-half reduction and some would have better protection than one two-hundredth reduction, but in the opinion of the OCDM the differences in the national totals would not be significant.

A factor of considerable significance, however, is that the above radiation casualty estimates are based on the $t^{-1.2}$ radiation decay rule, rather than on the most recent decay data developed by the Naval Radiological Defense Laboratory. Estimates based on the NRDL data, and subsequently presented by the OCDM at the request of Chairman Holifield, indicate that there would have been 5.1 million more fallout fatalities and 1.6 million more nonfatal fallout casualties than the $t^{-1.2}$ assumption indicated. The totals would then be 53.6 million fatalities and 20.5 million nonfatally injured.

It should also be noted in this connection that an upward revision of the estimated LD 50 rate (the radiation dose at which one-half those exposed would be expected to die), as suggested by some witnesses, would reduce the overall casualty estimates to some extent.

The subcommittee believes it is also important to note that almost 100 million of our people (56 percent of the population) would have survived this hypothetical attack without suffering blast, thermal, or serious fallout effects. Further, as pointed out by the OCDM, more than 96 million people in the United States do not live in or near likely target areas and could be expected to survive a nuclear attack merely through the provision of fallout shelter and a 2 weeks' supply of food and water.

The subcommittee recognizes that the long-range problems of a post-nuclear-war period would be extremely difficult, but this phase of recovery and rehabilitation was not within the scope of these particular hearings. A study of this aspect of national survival might well be explored by an appropriate committee of Congress.

TABLE V-2.—Effects on individual metropolitan areas

[In thousands]

Target area and weapons	Number of people in attacked areas ¹	Number killed 1st day	Number fatally injured	Number surviving injured
Two 10-megaton weapons each:				
Boston.....	2,875	1,052	1,084	467
Chicago.....	5,498	645	447	648
Detroit.....	3,017	820	593	557
Los Angeles.....	4,367	693	2,136	814
New York City.....	12,904	3,464	2,684	2,278
Philadelphia.....	3,071	1,309	989	777
Subtotal.....	32,332	7,888	7,883	5,541
One 10- and one 8-megaton weapon each:				
Baltimore.....	1,338	591	466	174
Cleveland.....	1,466	394	298	316
Pittsburgh.....	2,214	597	659	43
St. Louis.....	1,292	563	370	161
San Francisco.....	2,241	734	769	301
Washington, D.C.....	1,465	579	433	228
Subtotal.....	10,016	3,458	2,995	1,223
One 10-megaton weapon each:				
Atlanta.....	672	155	206	160
Buffalo.....	1,080	253	140	158
Cincinnati.....	904	461	261	93
Dallas.....	614	130	314	124
Houston.....	807	81	57	114
Kansas City.....	814	265	230	144
Milwaukee.....	872	151	112	189
Minneapolis.....	1,117	201	92	97
New Orleans.....	685	319	226	74
Portland.....	705	156	103	131
Providence.....	682	210	263	144
Seattle.....	732	168	99	126
Subtotal.....	9,693	2,550	2,103	1,554
One 8-megaton weapon each:				
Albany.....	514	69	51	63
Birmingham.....	559	159	137	86
Columbus.....	504	245	134	54
Dayton.....	458	200	119	58
Denver.....	564	138	144	118
Indianapolis.....	552	137	88	109
Louisville.....	577	264	156	59
Memphis.....	482	76	51	97
Norfolk.....	446	180	117	59
Rochester.....	488	212	107	59
San Diego.....	557	58	202	126
Youngstown.....	529	121	189	76
Subtotal.....	6,230	1,859	1,495	964
One 3- and one 2-megaton weapon each:				
Akron.....	410	162	104	66
Allentown.....	436	45	79	117
Fort Worth.....	361	73	189	74
Hartford (New Britain).....	539	124	110	119
Springfield-Holyoke.....	456	157	100	72
Toledo.....	396	107	74	75
Wilkes-Barre.....	393	51	48	63
Subtotal.....	2,991	719	704	586
One 3-megaton weapon each:				
Bridgeport.....	504	105	84	54
Canton.....	283	84	59	42
Chattanooga.....	246	85	77	29
Davenport.....	234	73	53	53
Erle.....	219	54	42	42
Flint.....	271	77	46	39
Grand Rapids.....	287	124	66	21
Knoxville.....	337	112	106	38
Launcester.....	235	64	51	49
New Haven (Waterbury).....	546	192	138	95
Peoria.....	250	84	54	28
Reading.....	256	72	66	60
South Bend.....	205	84	53	34

See footnote at end of table, p. 20.

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TABLE V-2.—*Effects on individual metropolitan areas—Continued*

[In thousands]

Target area and weapons	Number of people in attacked areas ¹	Number killed 1st day	Number fatally injured	Number surviving injured
One 3-megaton weapon each—Continued				
Syracuse.....	342	89	68	73
Trenton.....	230	41	80	97
Utica-Rome.....	284	107	60	2
Wheeling.....	355	59	58	46
Wichita.....	222	78	75	38
Wilmington.....	269	77	76	67
Worcester.....	547	123	151	97
Subtotal.....	6,122	1,779	1,463	1,004
One 1-megaton weapon each:				
Binghamton.....	185	58	32	17
Evansville.....	161	60	34	23
Fort Wayne.....	184	69	41	23
Greensboro.....	191	28	19	82
New Britain (included with Hartford).				
Rockford.....	152	42	25	25
Waterbury (included with New Haven).				
York.....	203	46	31	17
Subtotal.....	1,076	303	182	137
City target area total.....	68,460	18,556	16,825	11,009
Nontarget area total.....	82,239	1,095	5,354	6,182
Grand total.....	150,699	19,651	22,179	17,191

¹ 1950 population figures.

TABLE V-3.—*Effects of attack on individual States*

[In thousands]

State and region ¹	Number people in State ²	Number killed 1st day	Number fatally injured	Number surviving injured
Region 1:				
Connecticut.....	2,007	455	443	330
Maine.....	914	43	67	77
Massachusetts.....	4,691	1,347	1,501	878
New Hampshire.....	533	30	48	41
New Jersey.....	4,837	291	875	1,200
New York.....	14,830	4,067	2,702	2,123
Rhode Island.....	792	210	294	192
Vermont.....	378		18	24
Total.....	28,982	6,443	5,948	4,924
Region 2:				
Delaware.....	318	78	87	67
District of Columbia.....	803	440	257	75
Kentucky.....	2,945	344	246	149
Maryland.....	2,344	698	648	330
Ohio.....	7,948	1,657	1,421	1,089
Pennsylvania.....	10,495	2,164	2,134	1,723
Virginia.....	3,319	239	231	233
West Virginia.....	2,006	100	213	158
Total.....	30,178	5,720	5,237	3,824
Region 3:				
Alabama.....	3,062	169	263	248
Florida.....	2,771	90	271	245
Georgia.....	3,444	120	369	417
Mississippi.....	2,179	31	147	160
North Carolina.....	4,062	29	300	389
South Carolina.....	2,117	28	133	134
Tennessee.....	3,292	272	292	257
Total.....	20,927	739	1,775	1,850

See footnotes at end of table, p. 21.

BIOLOGICAL AND ENVIRONMENTAL EFFECTS OF NUCLEAR WAR 21

TABLE V-3.—*Effects of attack on individual States—Continued*

[In thousands]

State and region ¹	Number people in State ²	Number killed 1st day	Number fatally injured	Number surviving injured
Region 4:				
Illinois.....	8,714	726	686	873
Indiana.....	3,935	370	371	388
Michigan.....	6,371	1,020	738	694
Missouri.....	3,953	801	594	321
Wisconsin.....	3,435	172	148	258
Total.....	26,408	3,089	2,537	2,539
Region 5:				
Arkansas.....	1,910	4	59	43
Louisiana.....	2,683	420	443	291
New Mexico.....	681	92	108	75
Oklahoma.....	2,234	37	166	172
Texas.....	7,710	618	1,318	858
Total.....	15,218	1,171	2,094	1,439
Region 6:				
Colorado.....	1,326	167	205	174
Iowa.....	2,621	88	66	58
Kansas.....	1,905	113	155	146
Minnesota.....	2,983	15	17	50
Nebraska.....	1,325	43	47	84
North Dakota.....	620	5	5	12
South Dakota.....	653	1	3	10
Wyoming.....	291	32	16
Total.....	11,724	464	514	534
Region 7:				
Arizona.....	750	58	90	82
California.....	10,585	1,547	3,598	1,509
Nevada.....	160	23	28
Utah.....	689	9	16	27
Total.....	12,184	1,614	3,727	1,637
Region 8:				
Idaho.....	588	10	20
Montana.....	591	2	7	16
Oregon.....	1,521	156	99	114
Washington.....	2,378	253	231	294
Total.....	5,078	411	347	444
Grand total.....	160,699	19,651	22,179	17,191

¹ OCDM regions.

² 1950 population figures.

VI. CHARACTERISTICS OF RADIOACTIVE FALLOUT

Data concerning the characteristics of radioactive fallout were presented to the subcommittee in three general categories: worldwide fallout; basic properties and effects of fallout; and factors modifying the behavior of radioactive deposits.

WORLDWIDE FALLOUT

The charts appearing in figures VI-1 and 2 were prepared by Dr. Lester Machta of the U.S. Weather Bureau to illustrate the worldwide strontium 90 fallout and the total strontium 90 fallout on the United States which would result from the subcommittee's attack assumptions. While these charts depict only strontium 90, the results can also be applied roughly to cesium 137.⁹

⁹ For purposes of simplification, short-lived radionuclides were not included in this presentation. There is information suggesting that these short-lived radionuclides could contribute an appreciable portion of the worldwide fallout dose.

Production of radioactive debris

The total megatonnage of weapons detonated in the subcommittee's attack assumptions was approximately 4,000 (1,500 on the United States and 2,500 elsewhere in the Northern Hemisphere). Fifty percent of the energy from each weapon was assumed to be derived from fission, for a total of 2,000 megatons of weapon yield energy equivalent of fission products. Each megaton of fission energy creates approximately 100,000 curies of strontium 90. Thus, the 2,000-megaton energy equivalent of fission produced 200 million curies of strontium 90. These curies are divided roughly as follows: 80 percent is deposited in local fallout, 15 percent in stratospheric fallout, and 5 percent in tropospheric fallout. Approximately 20 percent of the 200 million curies go into worldwide dispersal.¹⁰

In the United States, the local fallout deposition was calculated by the OCDM based on the idealized model contained in "The Effects of Nuclear Weapons" handbook. Since estimates of the total (local plus worldwide) as well as the worldwide strontium 90 fallout are desired for the United States, it is necessary to convert the external dose to the strontium 90 which is associated with the gamma emitting fission products. Based on "The Effects of Nuclear Weapons" handbook, and allowing a small correction for shielding of particles in the ground, it is assumed that 1 roentgen per hour at 1 hour is equivalent to 100 millicuries (i.e., 0.1 curie) of strontium 90 per square mile in local fallout. This type of estimating is, of course, very rough.

Distribution of the worldwide fallout

The tropospheric strontium 90 is carried rapidly around the world in a generally west-to-east direction. It spreads in a north-south direction slowly so that the peak fallout is roughly in the latitude of the war area. The stratospheric fallout is deposited entirely in the Northern Hemisphere, peaked at about 45° N. and tapering off toward the Equator and North Pole. Both tropospheric and stratospheric fallout are brought down mainly with falling rain or snow; most of the tropospheric within about a month after the war and the stratospheric within a few months to a few years. The observed rainfall for the first month after mid-October 1958 was used in estimating the tropospheric fallout, and the average annual rainfall, weighted slightly to give spring rains a greater effectiveness, was the basis for the stratospheric deposition pattern.

The peak accumulation of strontium-90 in most places will probably occur in about 3 to 5 years after the attack. During this period about 10 percent of the strontium 90 produced will have decayed. Within the areas of heaviest local fallout, where levels are greater than about 10,000 millicuries of strontium 90 per square mile (see fig. VI-2) radioactive decay will be greater than the added tropospheric and stratospheric fallout and the peak values will occur at the time of the attack. Beyond 3 to 5 years following the war, the changes in deposited strontium 90 fallout are principally due to radioactive decay; 2½ percent of the remaining strontium 90 is lost each year.

Figure VI-1 is a polar stereographic projection of the Northern Hemisphere, showing isolines of worldwide strontium 90 deposition

¹⁰ The above figures are based on the difficult-to-substantiate assumption of "no fractionation" of the radioactive debris. That is, the percentages given above are assumed to apply equally to every fission product, specifically strontium 90. See p. 24.

WORLD-WIDE STRONTIUM-90 FALLOUT - mc/mi²

Pattern as of 3 to 5 years after attack

Local fallout omitted

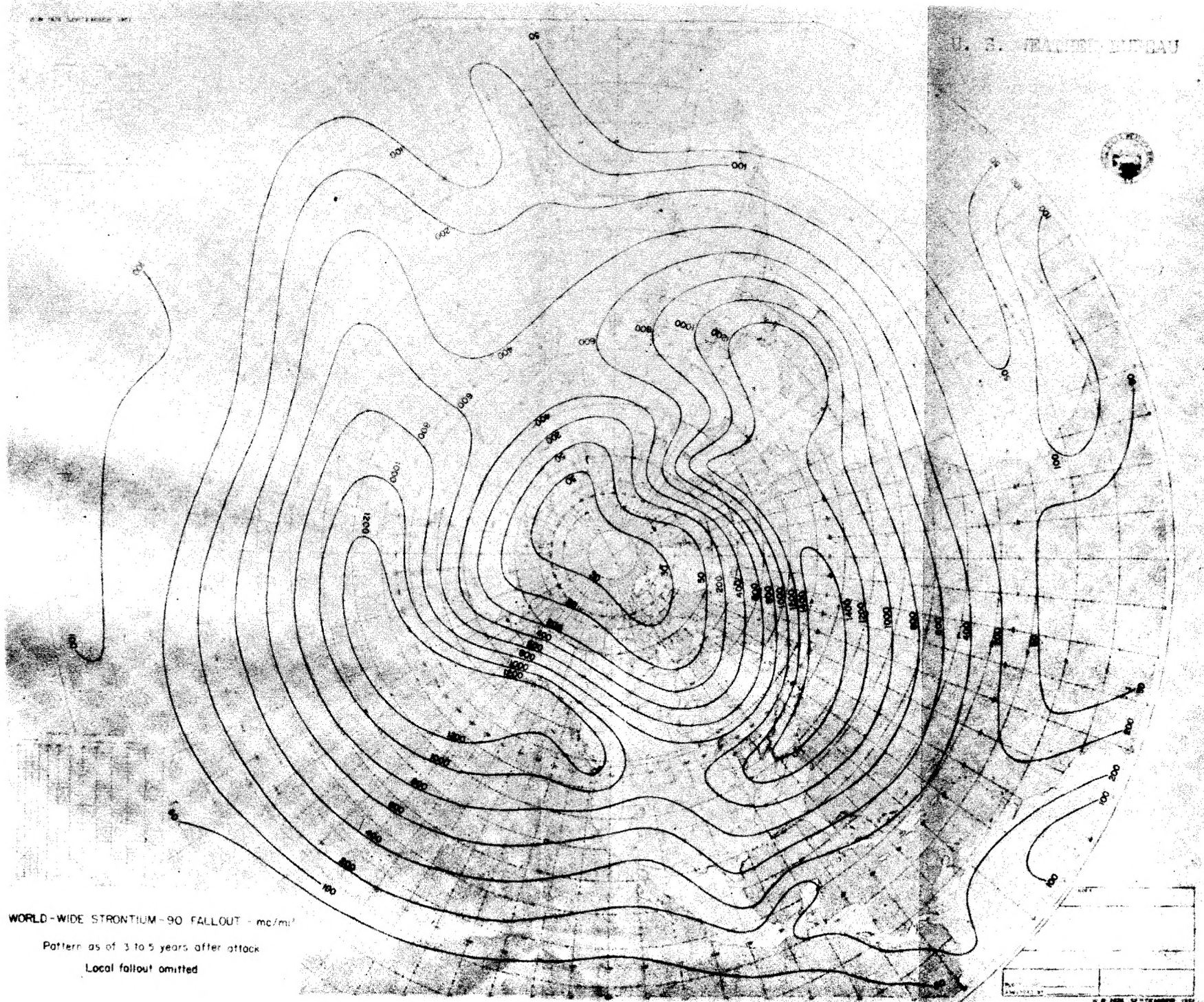


FIGURE VI-1

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genetic and somatic hazards to the populations of these countries have to be recognized.

Cesium 137 and carbon 14

The isolines on the maps may be readily, but only approximately, converted from strontium 90 to cesium 137 by simply multiplying by 2. About twice as many cesium 137 atoms as strontium 90 atoms are formed by the nuclear explosives. The half-life of the two substances are almost identical and it is assumed that they do not fractionate with respect to one another, that is, there is no tendency for more of one than the other to be deposited in local or worldwide fallout. The biological availability of cesium 137 does, however, differ from that of strontium 90.

The radioactive carbon 14, which presents a genetic hazard following a nuclear war, is present in the form of carbon dioxide when in the atmosphere. The natural carbon dioxide of the air also contains cosmic ray carbon 14 radioactivity in small amounts from which it is possible to compute its very small dosage of ionizing radiation to man. If the level of carbon 14 is raised, the dosage to man will also increase.

There is considerable uncertainty as to the amount of carbon 14 that would be created during the hypothetical situation set forth by the subcommittee. For purposes of this exercise, however, it may be noted that large quantities of carbon 14 would be added to the atmosphere, mainly the stratosphere.¹¹ Within a few years after the attack, the added carbon 14 would be mixed with the troposphere and the biosphere. At this time, before mixing with the Southern Hemisphere and the surface layers of the oceans is complete, the carbon 14 in the ground level Northern Hemisphere air may rise to about 20 times natural cosmic ray carbon 14 background. After several years to tens of years later, mainly as a result of mixing with the surface layers of the oceans, the excess carbon 14 will be halved. Then gradually over a period of several hundreds of years mixing with the large carbon reservoir of the deep oceans the weapon-created carbon 14 in the lower atmosphere and biosphere will be reduced to less than 50 percent of natural background. Continued radioactive decay will very slowly decrease the excess carbon 14 after mixing is complete. The half-life of carbon 14 is 5,600 years, so the rate of decay is indeed slow.

BASIC PROPERTIES OF RADIOACTIVE FALLOUT

General description of the mechanisms of formation

When the nucleus of a heavy atom like uranium is split by nuclear fission, or the nuclei of two light atoms such as hydrogen are combined by nuclear fusion, a part of the mass of these materials is lost in the process and is converted into energy. This process gives rise to a large number of neutrons, and gamma rays, as well as the almost instantaneous creation of great quantities of heat in the immediate vicinity of the nuclear explosion products. The neutrons, traveling outward from the explosion with almost the speed of light, can react with materials in the environment and induce radioactivity into these materials by a process very similar to that which is used in the manufacture of radioisotopes in nuclear reactors. Neutrons are

¹¹ Testimony based on weapons test experience indicates that approximately 8×10^{10} (800 billion billion) carbon 14 atoms would be added.

generated both by the fission process and the fusion process. The quantities of radioactive isotopes induced in the environment are about the same regardless of the design of the weapon. With weapon yields of the order of megatons used in the subcommittee's hypothetical attack, the radioactivity produced by this activation process may be quite significant.

There are over 40 ways in which a heavy nucleus such as uranium or plutonium can divide in the process of nuclear fission, leading to the production of 80 to 90 primary radioactive products. These products in turn decay very rapidly at the start so that the fission mixture soon consists of some 200 radioactive species. It is the gamma radiation emitted in the process of radioactive decay of these fission products that is of most concern in local fallout.

During the first few thousandths of a second of the explosion, all of the material in the weapon, including the radioactive explosion products, and the material in the immediate vicinity of the weapon in the environment are completely vaporized. This high temperature gives rise to the fireball which expands rapidly, heating the material in the environment as it expands. At the same time the fireball starts to rise. Therefore, the initial part of the explosion creates a mixture of gaseous material, melted material, and perhaps some partially melted environmental material.

As the fireball cools, the melted material begins to solidify and the gaseous material begins to condense. Materials with very high melting or boiling points such as iron, of course, condense first. Similarly, the radioactive elements with similar boiling points will tend to condense at the same time leaving the more gaseous components behind. Therefore, the radioactive species are incorporated into particles in the fireball in a nonuniform manner. Also, as the fireball rises violent winds are created, which suck into the hot fireball large quantities of soil. Small, molten particles tend to condense onto this material. This debris from the immediate environment, whether it be soil or water, becomes thoroughly mixed with the radioactive products from the explosion very much like flavoring is mixed into a cake batter. It is these heavy dirt particles, "flavored" with small quantities of radioactive debris, which return rapidly to the earth and are called local fallout.

Properties of fallout material from a land-surface detonation

A summary of the gross physical properties of the fallout material collected at two distances, one 8 miles downwind from the point of detonation and the other 60 miles downwind from the point of detonation is shown in table VI-1. All direct measurements of the physical properties of radioactive fallout material have been made in connection with the weapon-test program and from this point of view the information is artificial. The test fallout debris from detonations on a tower are, of course, the result of the vaporization of a large amount of either iron or aluminum used in the construction of the test towers. Only low-yield weapons have been detonated on the ground at Nevada, where the soil is coarse and sandy. All large yield land surface detonations conducted by the United States have been detonated on the coral atolls in the South Pacific. Therefore, this environmental material has the chemical composition of the coral. Just what the properties of the fallout material would be for a deto-

nation on clay or loam, or in a metropolitan industrial complex such as a city is not known.

From table VI-1 it can be seen that the particle size of the debris descending at a distance of 8 miles from the point of detonation is expected to be relatively large, whereas the average size of the material depositing at 60 miles downwind is relatively smaller. By comparison, the material drawn into the stratosphere and which contributes to worldwide fallout probably has a particle size of the order of 0.02 millimeter. Attention is called to the fact that the distribution of radioactivity within the fallout particles themselves is quite irregular and that the bulk of the radioactivity associated with these particles is related to the particle size. It is significant that the largest particles contain the most radioactivity.

TABLE VI-1.—Physical properties of land-surface burst fallout

Properties of particles ¹	~8-mile downwind ²	~60-mile downwind
General description.....	Melted, glassy solid containing air bubbles and mineral grains	air bubbles and mineral grains
Range of diameters.....	~0.075 to 1.5 millimeters.....	~0.050 to 0.30 millimeter.
Predominant size.....	~0.35 millimeter in diameter.....	~0.10 millimeter in diameter.
Color.....	Transparent to opaque, pale green or yellow to brown or black	
Shape.....	Spherical to irregular	
Specific gravity.....	~1.4 to 2.6 gm/cm ³	
Distribution of radioactivity.....	Irregularly throughout	
Relation of radioactivity to size.....	$\frac{A\alpha D_{max}}{D_{max}^3}$ but with the range of A increasing with D_{max}	

¹ Based on properties of particles from kiloton bursts on silicate sand; all other information derived from megaton bursts on coral sand.

² ~: Approximately.

The chemical and radiochemical properties of the fallout material from a land-surface burst is summarized in the printed hearings. Less than 3 percent of the radioactivity associated with these large particles is soluble by leaching with water for several days. This implies that the radioactivity associated with these particles is not available for incorporation into plants and animals, at least for short periods of exposure to the elements. There is a significant list of radioactive isotopes which can be induced, either by neutron activation of materials within the weapon, or by activation of materials within the immediate environment, which under various conditions can contribute quite significantly to the quantity of gamma radiation associated with this fallout material. Testimony presented at the hearings indicated that the presence of such induced activities should be recognized and their presence ignored only after positive evaluation has indicated that it may be proper to do so.

Finally, it may be noted that under the conditions suggested in this exercise, as much as 90 to 95 percent of the fission products generated by the explosion could be found in the close-in or local fallout. This, of course, includes virtually all of the important gamma-emitting radioactive isotopes. However, due to the mechanism of formation as indicated in the preceding section, it is noted that only around 50 percent or less of the important isotopes strontium 90 and cesium 137 are found in the local fallout. Due to the mechanism of formation this fraction is highly variable but the general implication is that due to fractionation the gamma-emitting radioactive materials

which can create a radiation threat from fallout under conditions of nuclear war are preferentially pulled down in the local fallout, whereas the long-lived isotopes which are significant in worldwide fallout and as possible sources of difficulty under conditions of the testing of nuclear weapons in times of peace, are preferentially distributed through the worldwide fallout. These fractions are also very highly variable and are quite sensitive to the precise conditions of the detonation. For surface bursts the standard estimate from the weapon-test program is to assume 80 percent of the total weapon debris deposits as close-in fallout, 15 percent appears as stratospheric fallout, and 5 percent remains in the troposphere.

The ability of gamma radiation to penetrate through solid materials such as would be found in the walls of structures is directly related to the energy of the radiation. Naturally, with a mixture as diverse as that of the fission mixture, the range of the energies from the gamma radiation is quite wide. It varies from as low as 0.01 Mev.¹² to as high as 2.5 Mev. It is, however, of considerable interest to see how the average energy of this complex mixture will change as a function of time. These data are shown in table VI-2.

TABLE VI-2.—Radiation characteristics of land-surface burst fallout

[In million electron volts]

Characteristics	8-mile downwind	60-mile downwind
Ionization decay rate: Average energy:		
1 hour.....		1.0
2 hours.....		0.95
½ day.....		.60
1 day.....		.40
1 week.....	0.25	.35
1 month.....	.45	.65
2 months.....	.55	.65
1 year.....		.55

Arrival and deposition characteristics

The principal arrival and deposition characteristics of a land surface detonation are summarized in table VI-3. At a distance of 8 miles from a 5-megaton detonation, the first fallout material can be expected to start arriving about 15 minutes after the detonation, to reach its peak at about 1.5 hours, and to be essentially completed in 6 hours. The total mass of dirt would amount to several tons per square mile at this distance, and the major portion would carry no radioactive material at all. However, a portion would carry radioactive debris, and the gamma radiation dose rate would start increasing at the time the first material arrived.

The gamma radiation rate would continue to increase for about 2½ hours, at which time the rate of radioactive decay would become equal to the rate of replenishment and the dose rate would level off and start decreasing by the end of 4 hours. After 6 hours, when the fallout ceased, the dose rate would diminish with a rate characteristic of the mixture of radioactive species that was present at that point.

At a distance of 60 miles, the time sequence would be very much the same, but slower. Fallout material would start arriving at about 7 hours after the detonation. It would reach a peak at 13 to 14

¹² Mev.: A unit of energy expressed in millions of electron volts.

hours and would be over in about 16 hours. The gamma radiation dose rate would reach a peak value at 10 to 14 hours after the detonation.

The total mass of material at either distance could amount to as much as 100 tons per square mile or more and the radiation intensities at either locality could be that associated with 1,000 roentgens per hour (measured at 1 hour after detonation). However, people at the closer location could receive about 6,000 roentgens more actual dose due to the 6- to 7-hour difference in the arrival time of the fallout.

TABLE VI-3.—*Arrival and deposition characteristic of land-surface burst fallout*

Characteristics	~8-mile downwind	~60-mile downwind
Time of arrival.....	~0.25 hour since detonation.....	~7 hours since detonation.
Time of peak.....	~1.5 hours since detonation.....	~13.5 hours since detonation.
Time of cessation.....	~6 hours since detonation.....	~16 hours since detonation.

Deviations with other detonation conditions

The information summarized so far is what would be expected from nuclear weapons detonated on the land surface as prescribed for this exercise. However, other detonation conditions which might be encountered in an actual attack would lead to different relations among these effects. The most important of these are summarized as follows:

1. An airburst produces little to no local fallout. The weapon debris condenses in highly soluble (50 percent or more), very small particles (less than 1 micron). The effective ranges of the blast effect, particularly at moderate damage levels, and thermal radiation become more important than the immediate nuclear radiation as the height of detonation is increased.

2. A detonation under sea water results in the formation of water and concentrated salt solution drops which, on drying, are more difficult to remove than dry dirt from a land-surface detonation. About 50 percent or more of the radioactive material is soluble and available for incorporation into food. Also, the water, with its lower boiling point, causes much less fractionation of the mixture of fission products, leading to less distortion of the radioactive decay characteristics.

Dose rate to total dose relations

Testimony presented at the hearings indicated that the actual release of gamma radiation energy from the fission products differs significantly from that represented by the $t^{-1.2}$ rule and other information given in the official Government publication "The Effects of Nuclear Weapons." Because of its significance to the estimates used in connection with these hearings, this point will be discussed in some detail.

From data in "The Effects of Nuclear Weapons," if the unfractionated fission products created from the detonation of 1-kiloton equivalent of nuclear explosion are deposited uniformly over 1 square mile, the contamination density (fission product density) will be equivalent to 300 gamma megacuries at 1 hour after the detonation. The corresponding gamma radiation emission rate¹³ can be converted to the gamma radiation dose rate on the basis that the average energy

¹³ The gamma emission rate describes the flux of nuclear radiation being emitted by a source. The gamma radiation dose rate describes the absorption of these radiations by the body.

of the gamma photons is 0.7 Mev. The gamma radiation dose rate at 1 hour after detonation for a contamination density of 1 kiloton per square mile can be related to the gamma radiation dose rate at any subsequent time by the relation, $R_t/R_1=t^{-1.2}$. However, if the known facts concerning the formation and gamma emission properties of individual fission products are synthesized in tabular form, it is found that significant differences exist between these results and those computed by means of the standard formula. Data from one paper submitted to the subcommittee in connection with the earlier hearings on the effects of the weapon test program are reproduced in table VI-4. It can be seen from this table that the gamma radiation dose rate from the fission products of 1 kiloton nuclear yield per square mile at 1 hour is 2.7 times greater than that computed by the standard formula. Also, it can be seen that the total gamma radiation dose accumulated from 1 hour to 3 days is about 7,800 roentgens compared to 3,400 roentgens computed from the standard formula. Therefore, the magnitude of the gamma radiation threat from the fission products in fallout is greater than that calculated by means of the standard formula by a factor of about 2.

However, it can be seen that at 1 year the gamma radiation dose rate computed from the synthesis of the known fission products which could be present, is only about one-half that which is computed by the standard formula. At 3 years it is about one-seventh. This information is significant with regard to the estimation of the length of time an area might be denied to normal occupancy as the result of radioactive fallout.

TABLE VI-4.—Comparison of gamma dose rates and integrated doses for uniform contamination level of 1 kiloton of fission products per square mile, contrasting the "Effects of Nuclear Weapons" handbook data ($t^{-1.2}$) with more recent computations developed by the U.S. Naval Radiological Defense Laboratory

Time after detonation	Dose rate (roentgens per hour 3 feet above infinite plane)			Integrated dose from 1 hour (roentgens 3 feet above infinite plane)	
	Effects of nuclear weapons	NRDL—TR-247	Ratio NRDL/ENW	Effects of nuclear weapons	NRDL—TR-247
1 hour.....	1,260	3,360	2.7	0	0
2 hours.....	548	1,416	2.6	815	2,199
6 hours.....	147	317	2.2	1,898	4,706
12 hours.....	64	142	2.2	2,467	5,960
24 hours.....	28	55	2.0	2,964	7,012
48 hours.....	12.1	20.2	1.7	3,407	7,803
3 days.....	7.43	11.52	1.6	3,629	8,163
1 week.....	2.70	4.56	1.7	4,042	8,831
2 weeks.....	1.17	2.21	1.9	4,333	9,357
1 month.....	.483	.902	1.9	4,612	9,888
2 months.....	.204	.329	1.6	4,826	10,297
3 months.....	.126	.197	1.6	4,939	10,431
6 months.....	.0547	.0792	1.4	5,122	10,750
1 year.....	.0238	.0137	.58	5,273	10,953
2 years.....	.0104	.00185	.18	5,399	10,965
3 years.....	.00637	.00108	.17	5,475	10,979
5 years.....	3.45×10^{-3}	6.24×10^{-4}	.18	5,557	11,002
10 years.....	1.50×10^{-3}	4.80×10^{-4}	.32	5,657	11,040
20 years.....	6.52×10^{-4}	3.94×10^{-4}	.63	5,735	11,071
30 years.....	4.01×10^{-4}	3.26×10^{-4}	.81	5,782	11,136
60 years.....	1.75×10^{-4}	1.82×10^{-4}	1.04	5,847	11,133
100 years.....	9.46×10^{-5}	8.12×10^{-5}	.96	6,080	

Since it is customary to convert measurements of roentgens per hour at 1 hour to a fission product density per square mile and from this conversion to compute the fraction of the fallout debris including such isotopes as strontium 90 and cesium 137 deposited in the close-in fallout region, it is clear that this information has a direct bearing on computations involving the distribution of fission product debris between close-in and worldwide fallout.

Additional information derived from testimony presented at the hearings, and considered by the technical panel covering the weapons effects problems, is the observation that nonfission product activities such as neptunium 239, uranium 237, uranium 240, sodium 24, manganese 56, and others, may also be present in the close-in fallout. Their gamma radiations may account for a substantial fraction of the open field roentgen dose particularly between the times of 8 hours and 1 week. These contributions, of course, would be in addition to the values already indicated in table VI-4 and would affect the conversion from gamma dose rate to strontium 90.

It was the consensus of the panel members that these differences from the standard formula would not seriously affect the validity of the relative estimates used for this exercise, but that the approximate nature of the estimates must be recognized when other applications are considered.

FACTORS MODIFYING BEHAVIOR OF RADIOACTIVE DEPOSITS

Effect of wind and weather

It was the consensus among all the experts testifying before the subcommittee that the weather plays a major role in determining the location and distribution of radioactive fallout. The weapon and environmental debris is carried by the wind far from the point of detonation as it settles through the atmosphere. Since the wind at different altitudes and in different sections of the country may differ considerably both as to direction and speed, the actual fallout contours encountered in reality differ markedly from the idealized cigar-shaped patterns normally used as the basis of estimating the fallout effects. Actual patterns measured in connection with the test program at the Nevada test site neither looked like a cigar nor had the smooth shape normally used. It was indicated that the irregularities are due to many factors, such as the complexities of the radioactivity distribution in the atomic cloud, the effect of water condensation within the mushroom, atmospheric turbulence, and the roughness of the ground on which the fallout takes place.

For purposes of estimates in connection with exercises such as the subcommittee's assumed attack situation, these irregularities were considered to be unimportant in evaluating casualties. However, in real fallout situations, the irregularities in the pattern complicate the work of evaluating the damage and forces one to rely almost entirely on measurements of radiation intensity at a given place rather than estimating them from nearby locations or from methods of prediction.

The principal differences that were indicated as affecting the location of the initial deposition on the ground may be summarized as follows:

(1) For a 5- to 10-megaton yield weapon detonated on the ground, the maximum fallout intensity may appear at a distance as great as 60 to 70 miles away from the original point of detonation.

(2) Not only is the deposition pattern irregular, but isolated "hot spots" appear at irregular locations both as to direction and distance in relation to the main axis of the deposition pattern. An illustrative example is shown in figure VI-1.

(3) One isolated "hot spot" with a radioactivity intensity about seven times greater than that in the immediate surroundings has been observed on the immediate downwind side of a mountain range. It was indicated that this, or the fact that some light rain was reported in the area at the time, may have contributed to the observation.

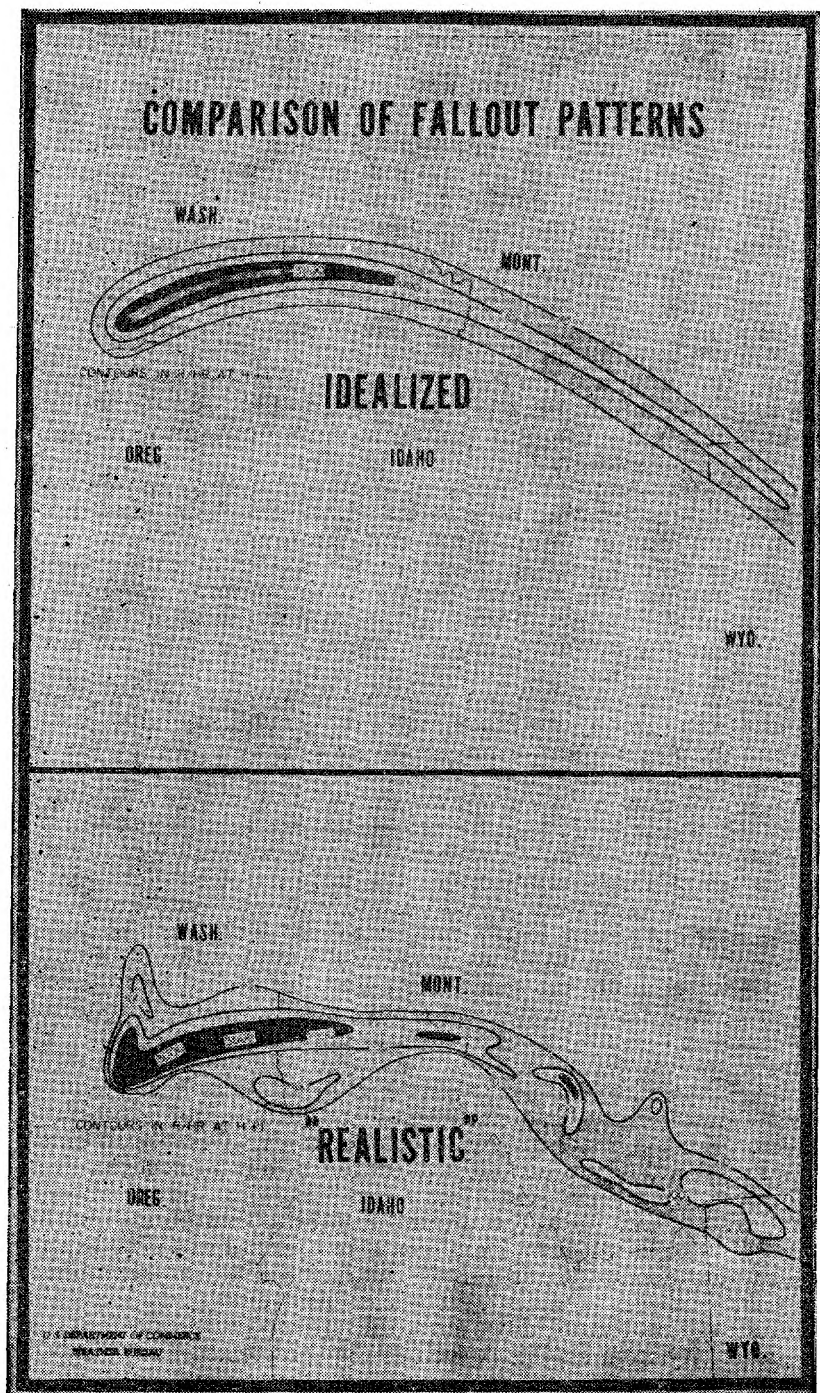
(4) It was stated that theoretical studies suggest the possibility that the airflow patterns over mountain ranges may be such that the location of the fallout deposition will not be affected. Normal terrain features whose dimensions are small in relation to the vertical and horizontal dimension of the radioactive cloud are considered to have relatively minor influences on the overall deposition of the fallout debris. For example, the tendency for winds to flow up a valley in the daytime and down the valley at night would not be expected to cause a major distortion in the total amount of radioactive debris deposited in the valley.

(5) The testimony indicated that the thermal column produced by large scale fires resulting from nuclear detonations may considerably alter the fallout deposition pattern if the fires are well developed before the fallout arrives. However, Dr. Lester Machta expressed the opinion that wind currents created by the nuclear explosion or by subsequent fires will not appreciably modify nature's winds, and hence, by implication, would not cause a major distortion on the fallout deposit as a whole.

Once the fallout debris has deposited on the ground the primary factors which modify the fallout field are rain and ground level wind. Runoff from rain modifies the fallout field by carrying the particles from one location to another. Therefore, weathering is expected to be more effective with sloping terrain and less porous soil, and the radioactive debris will tend to accumulate in collection areas such as drainage regions. Smooth surfaces like streets or other paved areas retain the particles very poorly. The majority of the debris in this case would be expected to run off into sewers or onto nearby soil. Testimony submitted to the committee also indicated that rainfall generally infiltrates into the ground and the insoluble particles are thereby carried into the soil rather than being eroded away. About 10 percent of the deposited radioactive debris was testified as being the amount that might be expected to ultimately appear in a water-supply system.

Wind velocities of greater than 10 to 15 miles per hour are needed to initiate wind erosion of particles as large as those in the local fallout areas. Erosion from highly vegetated areas is negligible. In general, wind erosion tends to make the deposited fallout field more uniform. However, on a small scale, just as with blowing snow, radioactive particles can pile up in certain preferred areas and be scoured from others. The behavior of the radioactive particles would be expected to be very similar to that of the nonradioactive material normally present in the environment. The consensus among the expert witnesses was that one could not expect nature to significantly reduce the radioactivity from an attack such as that predicated by the subcom-

FIGURE VI-1



mittee through the influence of natural weathering forces. The countermeasures will have to be man's own doing.

An analysis of the rainfall and wind patterns for the 2 weeks following the date of the hypothetical attack showed that the largest region of rainfall occurred in the eastern part of the United States from Ohio to Maine. In these areas although the rain was not heavy some benefit could be expected through washing the radioactive debris from the roofs and streets during the early part of the fallout period.

High winds occurred only in the northern Midwest region where the fallout deposition was sparse.

The effect of terrain and builtupness on the radiation

The previous section considered the influence of meteorology and terrain on the deposition of the fallout material. This material, which is the source of the nuclear radiation, is associated with the deposit. Therefore, the deposition information is related to a knowledge of where the maximum fallout threat may be expected to occur. However, the nuclear radiations from radioactive decay are also influenced by the environment. It is therefore of some interest to examine the effect of different orientations between the deposited material and the environment which may influence the subsequent behavior of the gamma radiation that is emitted.

According to testimony presented at the hearings, approximately one-half of the total dose to which a person standing in a flat area is exposed, originates within a radius of about 30 feet. From data already presented, it is clear that a person in such a position would not only be exposed to radiation from the material already deposited on a flat terrain, but would also be subjected to radiation originating from material in the cloud prior to the time the deposition was complete. The manner in which the radiation dose, hence, the radiation threat, might be distributed between these two conditions was not examined specifically in the course of the hearings. The following points with respect to the influence of the terrain on the radiation field resulting from material already deposited were brought out:

(1) The radiation intensity numbers used in connection with the standard scaling formulas are based on direct measurements of the fallout pattern on the ground. Therefore, they already incorporate the effects of induced activities that might be present, the effect of terrain at the point of measurement, and the effect due to the thickness of the deposit. These values would not be expected to agree precisely with those computed from the fission product density and the radioactivity characteristics of the fission products.

(2) A roughness of terrain ranging between that of a smooth concrete slab and that of a wooded hilly field decreased the radiation intensity at a standard height above the ground by approximately one-third of the radiation intensity computed by the "billiard table" reference condition. The degree of change was roughly proportional to the degree of roughness.

(3) An actual fallout deposit under experimental circumstances behaved as though it were uniformly mixed to a depth of about one inch in the soil. This implies that all computations based upon the standard reference condition of an infinite flat plane will be too high.

(4) Under the standard reference condition, the radiation intensity at the center of a partially cleared area, decreases continuously with

altitude. In the real case, as a result of the fact that the material is not in a perfect terrain but has a finite depth, the radiation intensity first increases with altitude and then decreases as the height of the point over the cleared area is increased.

(5) The ratio of observed to calculated radiation intensities has also been found to vary with time. It was reported that in at least one case for measurements made in the Pacific, a ratio of 0.45 was found at 11 hours, 0.66 between 100 and 200 hours, and 0.56 between 370 and 1,000 hours after the detonation.

(6) According to the testimony, the influence of vegetation and trees, which could elevate some of the fallout material above the surrounding ground level, is very small when compared to radiation emanating from material on the ground. Specific corrections to allow for the presence of vegetation are not currently incorporated in estimates of the radiation intensities generated at a point as the result of fallout deposition.

(7) When the fallout occurs over a community, a number of departures from the estimates for an infinite flat plane occur. Part of the fallout that would have been deposited on the ground is, instead, deposited on the roof. This has the effect of reducing the predicted intensity by placing the source a greater distance away from the point of concern near the ground and also results in interposing material in the building structure between the fallout and the point of concern. The resulting reduction in radiation intensity was estimated to be as little as a factor of 2 in light frame residential buildings of the 1-story design, to a factor of 10 to 20 in the basements of 2-story residential buildings made of heavy material such as brick. Testimony also indicated that moderately simple protective measures such as could be provided by a combination of tables and sandbags could reduce the radiation intensities by as much as a factor of 100 in such a basement.

(8) Due to the intense scattering of both the immediate gamma radiation and neutrons from air, there is very little protection afforded to one building because it is surrounded by others. The radiation protection from that portion of the radiation dose which might come from the immediate gamma and neutron radiation would be changed by less than 50 percent due to the presence of other structures.

VII. BIOLOGICAL EFFECTS

INTRODUCTION

The three basic casualty producing phenomena of a nuclear attack are (1) blast, (2) thermal, and (3) radiation. In an analysis of the biological effects of these phenomena it is necessary that they be considered singly and collectively and from the standpoint of the direct/prompt and the indirect/delayed effects.

Although it is unlikely that thermal burns, primary and secondary blast injuries, and radiation injury would occur singly in an appreciable portion of the casualties in those areas suffering heavy structural damage from weapons of any of the sizes employed in this attack, these effects were treated separately in the hearings in order that expert testimony from specialists in each field could be received.

Wherever possible, witnesses who have actively participated in human experience studies, i. e., the Hiroshima and Nagasaki surveys,

the Marshallese studies and the radiation accidents both in the United States and abroad were called.

In those areas where little or no human experience data exist, the most competent testimony, based upon extensive laboratory experimentation utilizing animals, was solicited.

BLAST EFFECTS

The biological effects of blast were considered in four categories:

(a) Primary blast effects which cause lung damage and rupture of the eardrums due to the direct effect of the pressure wave on the body. In terms of peak overpressure in pounds per square inch, nuclear weapons blasts with their relatively sustained overpressures are much more efficient producers of casualties by a factor of 10 or more than are equivalent high explosive blasts. Nevertheless, lung hemorrhage and broken eardrums were uncommon in Japan. With 1- to 10-megaton weapons lung damage would be restricted to from 2.5 to 5.5 miles, which is well within the zone of destruction of brick apartment houses (3 to 7 miles). Ruptured eardrums might occur farther out—4.5 to 7.7 miles. In other words, serious to fatal primary blast injury is unlikely to occur as an isolated event.

(b) Secondary blast effects due to flying fragments which become missiles created by the pressure wave. This pressure or blast wave would produce injurious effects by propelling loose debris, broken glass or ceramics, and building materials to a velocity high enough to penetrate the human body. This effect is important out to 5 miles from a 1-megaton surface detonation and 11 miles with a 10-megaton surface detonation.

(c) Tertiary effects resulting from the body itself being thrown violently by the pressure wave. Human beings may become missiles upon being picked up and hurled laterally by the blast wave. These injuries are similar to automobile and aircraft accidents, and can occur to distances of 3 to 5 miles from a 1-megaton surface detonation and 7 to 16 miles for a 10-megaton surface detonation.

(d) Miscellaneous injuries due to ground shock (broken legs), dust, fires created by destruction of buildings, power lines and gas mains.

It was estimated that about 5 percent of the hazard from a 10-megaton surface detonation could be related to casualties resulting directly from the pressure wave (primary effect), and that about 95 percent of the casualties would result from missiles (secondary effects) and displacement (tertiary effects). It was also pointed out that, based on "free field" effects (i.e., likened to conditions which would obtain on a perfectly flat surface) the combined effects (blast, thermal, and initial ionizing radiation) varied with weapon yield. However, the effects would be encountered in the following sequence and combinations as one moves away from the point of detonation:

	Fallout radiation	Thermal	Blast	Immediate radiation
Point of detonation	+	+	+	+
↓	+	+	+	+
Increasing distance from point of detonation	+	+	+	+
↓	+	+	+	+

Witnesses stressed the point that when a nuclear weapon is detonated in a densely populated area, a large population would be exposed to these immediate threats—blast, thermal, and immediate ionizing radiation. Dr. C. S. White summarized his analysis with this statement:

Even without introducing thinking regarding protection, the "very close in" residual radiation levels need to be known to aid understanding and estimating the "cost" of nuclear war to a nation whose population is practically "naked" and completely unprepared and unprotected for a full scale nuclear attack.

THERMAL EFFECTS

Since thermal radiation is transmitted on a "line of sight," the vulnerability of an object or person to this effect depends on the fireball being directly visible at that point. The following major points were brought out in the testimony regarding the thermal effects of a nuclear detonation:

(a) Thermal radiation can cause fires by direct ignition of combustible materials, skin burns on exposed portions of the body, and temporary or permanent blindness from the intense light.

(b) It takes about 1 second for the thermal output from a 1-megaton detonation to reach its peak intensity, and about 3 seconds for a 10-megaton detonation. Evasive action must be taken almost instantly if it is to be effective.

(c) Temporary or permanent blindness could be caused by the thermal radiation if a person is looking in the general direction of the fireball at the precise moment of detonation. The lens of the eye focuses heat as well as light rays on the retina of the eye. Thus in addition to temporary or "flash" blindness of a few seconds or minutes duration from the intense light, actual burns of the retina could occur from undue amount of thermal radiation entering the eye. Neither flash blindness or retinal damage constitute major hazards during daylight because of natural restriction of the diameter of the pupil which limits the amount of light entering the eye; furthermore the blink reflex, one hundred and fifty thousandths of a second, protects the eye from undue amounts of radiation, except in those cases where the thermal pulse is delivered within extremely short times. This is the case for low-yield weapons. However, in this attack involving weapons ranging in yield from 1 to 10 megatons, the hazards of retinal damage would be negligible.

(d) The thermal energy falling on a unit area¹⁸ which is required to cause flash burns was reported to be 7 to 9 calories per square centimeter to produce a second-degree burn from a 10-megaton weapon, 6 to 7 calories per square centimeter for a 1-megaton weapon, and 4 to 5 calories per square centimeter for a 100-kiloton weapon. It would take about 30 calories per square centimeter to ignite average clothing, and 5 to 10 calories per square centimeter to ignite many combustible materials such as newspaper, and cloth, with the 3-second pulse from a 10-megaton detonation.

(e) Under atmospheric conditions where the visibility is about 10 miles or more, thermal intensities of this magnitude can be obtained at maximum distances of 20 to 25 miles from the point of detonation. Therefore, the potentiality of mass fires (fire storms) is considered to

¹⁸ Normally expressed in terms of calories per square centimeter.

be a major threat from the detonation of nuclear weapons in densely populated areas.

(f) The consensus of testimony on this subject was that the combination of blast, fire, and radiation effects from megaton-yield weapons detonated in densely populated areas would be catastrophic in nature. Normal disaster aid facilities would be completely overwhelmed. Medical facilities and supplies would be inadequate to cope with the situation. Many of the injured who could normally be saved with good hospitalization and medical care would succumb to infection and shock.

ACUTE EFFECTS OF NUCLEAR RADIATION

The biological effects of nuclear radiation differ from blast and thermal effects in that the effect of exposure may not be apparent until hours, days, or weeks following the initial injury. The most severe form of radiation injury, under conditions of nuclear war, is that resulting from exposure of the whole body to high intensity nuclear radiation originating from the detonation. The discussion in this section will consider source conditions which can create lethal external radiation exposures in 48 hours or less which would lead to visible effects on the body within a time span of hours to weeks, and which are related to problems of immediate survival.

The sources of concern are the immediate nuclear radiations consisting of neutrons and gamma radiation, "throw out" or "very close-in" fallout, and "local fallout" which is deposited many miles downwind from the point of detonation within the first few hours. "Very close-in fallout," composed of very heavy particles, is relatively unaffected by meteorological conditions. These sources are capable of creating radiation exposure conditions of 1,000 to 5,000 roentgens in a time period of from thousandths of a second in the case of neutrons to several days in the case of local fallout.

Four categories of radiation disease related to the magnitude of the dose were described. These are—

(a) Hyperacute response due to instantaneous radiation doses of 5,000 roentgens or greater. Irrational behavior, general collapse and shocklike symptoms develop within minutes, and terminate in death within hours. This effect is not considered significant under nuclear-war conditions since it would occur within the lethal radius of the blast and thermal effects.

(b) Acute gastrointestinal syndrome (a collection of symptoms) created by radiation doses of 1,000 to 5,000 roentgens. The symptoms are nausea, vomiting, fever and general fatigue starting in a few hours. Temporary recovery occurs, but the symptoms reappear in 1 to 2 weeks. Death is probably inevitable soon thereafter.

(c) Hematopoietic (changes in composition of the blood) syndrome which is dominant in the dose range of 200 to 1,000 roentgens. In addition to subacute gastrointestinal effects leading to nausea and vomiting a few hours after exposure, major changes occur in the composition of the blood in the period of 2 to 4 weeks after exposure. The body is particularly susceptible to infections during this time. Recovery is possible, but not at all certain. Testimony indicated that approximately one-half

of the people exposed at the level of 450 to 700 roentgens would be expected to recover if they are not subjected to additional physical stress or radiation. The other one-half would be expected to die within 2 to 4 months. The probability of recovery is, of course, greater at the lower end of the dose scale (200 to 400 roentgens).

(d) No obvious disease. This category is related to exposures of 200 roentgens or less. Mild symptoms of nausea and vomiting may appear, as well as later (4 to 6 weeks) changes in the blood composition. However, these people do not require hospitalization and can function normally although they may be more sensitive to later radiation exposures than previously unexposed persons.

EFFECTS OF PROTRACTED RADIATION

The residual radiation from fallout will persist with gradually diminishing intensity for months, particularly in areas where the initial level corresponded to 1,000 roentgens per hour at 1 hour after the attack. The testimony regarding the biological consequences of such protracted radiation exposure conditions emphasized the following points:

(a) The body can tolerate higher exposures of radiation without developing symptoms of acute radiation illness if the exposure is spread over a longer period of time. This is a factor of great importance in a post-attack situation.

(b) With continued or repeated exposures, biological recovery from the injury progresses with a half-time of about a month, that is, one-half recovery from remaining effects for each succeeding month, but about 10 percent of the injury is not repairable. This nonrecoverable injury builds up a pool of damaged cells in the body and contributes to very late effects, such as cancer.

(c) When only a part of the body is exposed, the ability to recover is increased. The radiation resistance of animals has been doubled by protecting as little as 15 percent of the body.

(d) Animals irradiated below the lethal level by radiation doses in excess of 100 roentgens, die at an earlier age than normal. Estimates were submitted indicating that for the survivors of a nuclear attack, 1 roentgen would shorten the life expectancy by about 10 days. However, several witnesses contended that this estimate is much too high.¹⁴

(e) Experimental studies on mice indicated that spreading an exposure of 510 roentgens over 18 days was no more injurious than spreading the same exposure over 162 days based on measurements of survival time.

(f) The probability of increasing the incidence of leukemia and other types of cancer was considered to be proportional to the average total radiation dose sustained by the surviving population. Potential deaths from this cause were estimated to fall in the range of about 2 percent of the deaths attributable to acute radiation injury.

(g) Witnesses stressed that both the dose rates and total doses used in these experiments are directly comparable to exposure conditions that would be created by the hypothetical attack situation so that

¹⁴ Experimental evidence was cited showing that rats exposed at a dose rate of 0.1 roentgen per hour 8 hours a day for 1 year (total dose of 292 roentgens) had a longer life expectancy than their unirradiated controls. Similar observations have been reported from several laboratories.

estimates of the predicted acute effects on man can be based directly on experimental data.

SKIN BURNS FROM FALLOUT

The intensely radioactive fallout particles emit short-range beta radiations in addition to the penetrating gamma radiations. If fallout particles are lodged in direct contact with the skin, a skin burn can be created at that point. Doses in excess of 1,000 roentgens to the skin are required to produce severe burns. Good personal hygiene, by removing the fallout particles from the skin, can offset this effect. Beta burns, by creating open lesions, are easily infected. As a threat to survival, skin burns from fallout particles are much less important than the threat of whole-body gamma radiation under the exposure conditions of nuclear war. Pictures of actual skin burns on the Rongelap natives following the event of March 4, 1954, were displayed to the subcommittee during the hearings. It is significant to note that these burns were observed although the natives had been removed from the islands before a lethal dose of penetrating gamma radiation had accumulated. The testimony indicated that problems from this effect would become more significant during times of recovery when the threat to immediate survival had passed.

INHALATION HAZARD FROM FALLOUT

Little quantitative data is available on the inhalation hazard from fallout, but data from all field tests and on the Rongelap (Marshall Islanders) people as well as from inhalation experiments in animals all suggest that in a relatively heavy fallout field: (1) the dose to the lung is unimportant compared to the total body radiation from the fallout field itself, (2) the dose to the lung is less than to the gastrointestinal tract even in the absence of eating contaminated food, and (3) that the dose to the thyroid gland from the I^{131} (iodine) (because I^{131} concentrates there) could be the largest dose received by any single organ of the body, in the absence of shelter in some fallout exposure situations.

INGESTION HAZARD FROM FALLOUT

Ingestion of fallout debris could result in much larger internal radiation exposures than inhalation, yet still be of lesser concern than the external radiation for unshielded persons. During the critical weeks following the attack ingested fallout material would be almost entirely from surface contamination. The principal potential hazards from ingestion of fallout for several weeks after a nuclear detonation would be the exposure of the gastrointestinal tract itself and exposure to the thyroid gland from deposition of I^{131} therein.

Theoretical studies suggest that radiation doses to the adult thyroid may be two or more times greater than to the intestines from ingestion of fallout material during most of the critical period. However, a 1,000- to 2,000-roentgen dose to the intestines would threaten survival, whereas the adult thyroid can normally withstand tens of thousands of roentgens before serious effects occur. Children's thyroids are more sensitive and the chance of late cancer from irradiation would be

greater if the dose were received in childhood. Milk could present a special problem, since it can contain relatively large quantities of I^{131} but lesser proportions of the other fission products than present in the original fallout.

Additional testimony indicated that the accumulating deposition of radioactive elements in the human body would be comparable to the levels currently established as acceptable for occupational exposure. This source of exposure would not become a major threat to survival in the immediate postwar period.

GENETIC EFFECTS

The study of genetic effects of massive radiation on man is very limited. There is considerable evidence that the radiation exposure of a nuclear war would greatly increase genetic mutations for some succeeding generations. However, the widespread argument that the ultimate genetic consequences could lead to the virtual elimination of the human race is not supported by the testimony. The consensus of expert testimony was that the race could and would survive the type of hypothetical attack considered in these hearings, notwithstanding the inevitable costs in physical impairments and deaths due to additional genetic mutations.

An approximation was set forth by one key witness to the effect that if a portion of our surviving population had been subjected to a cumulative average exposure of from 500 to 1,000 roentgens the resulting mutations in this group would about equal in number those deleterious genes the human race already possesses.

However, it was also noted in supplementary information submitted by the OCDM at the request of the subcommittee that the average exposures to the surviving population in the United States under the assumed attack situation would be considerably less than the lower limit of 500 roentgens.

VIII. ENVIRONMENTAL CONTAMINATION

The testimony discussed in the previous sections has dealt primarily with immediate problems related to the survival of the population resulting from an all-out nuclear attack on this country. It is the purpose of this section to examine the long-time consequences resulting from the introduction of large quantities of radioactive materials into the environment. These consequences will be considered in three categories: (1) The effect on animals, (2) the effects on food supplies, and (3) the long-term ecological¹⁵ consequences resulting from the massive introduction of radioactive elements into the environment.

EFFECT ON ANIMALS

All domestic animals have a similar response to total body irradiation such as that encountered from fallout. Few, if any, die after exposure to 250 roentgens, and few survive a dose as high as 1,000 roentgens. The body size of the animal has little to do with its survival, although the very young or the very old may be more sensitive.

¹⁵ Ecology deals with the biology of the mutual relationships between living organisms and their environment.

The principal facts related to this topic are summarized in the following points:

1. There is no single clinical reaction for irradiation damage in animals. Complete collapse of the burro to an acute exposure in low lethal range is unique but may be observed in most other animals if high exposure doses are given rapidly. Following an exposure there are usually days of good health, this is followed by 4 or 5 days of apathy, followed by increased irritability, hyperesthesia, decreased food and water intake, and finally death or recovery. Animals usually die or recover within 3 or 4 weeks. There is always a latent period between irradiation and death.

2. The characteristic blood picture of the irradiation syndrome in animals is immediate decrease in numbers of white blood cells; a lesser and slower reduction and faster recovery of red blood cells; a slower clotting time and impaired clot retraction. Leukemia has been observed following total body irradiation of swine.

3. The immune response of animals to parasites and disease is affected by total body irradiation. Active immunities have been completely destroyed, however the response to the immunity of viruses, toxins, or bacteria is not always similar.

4. There are no distinctive effects of irradiation on the reproductive system. Doses in the lethal range are necessary to impair fertility. Lower exposures, at the proper time in gestation, may cause fetal aberrations. Genetic changes will not necessarily be deleterious due to the common practice of selective breeding.

5. Particulate matter in fallout has lodged sufficient radioactive material in the coats of grazing animals close to nuclear detonations to produce beta burns in the hides. These lesions are characterized by atrophy of the skin or necrosis depending upon the severity. They may heal completely, leave a smooth, weakened skin with discolored hair, or form permanent scar tissue. Experimentally it takes thousands of roentgens of beta radiation to cause a beta burn. None of the animals, accidentally exposed and observed has had other physical signs of exposure.

6. Limited experimental evidence and field testing indicate that animals in the path of a fallout which fail to develop beta burns will have been exposed to less than harmful external radiation and the radionuclides from that cloud will be practically innocuous to the grazing animal.

Animals that sustain exposure intense enough to produce beta burns but live longer than 3 weeks or a month fall into the same category as those without burns.

All other grazing animals will have received a fatal total body exposure dose and both external beta irradiation and irradiation from ingested sources are of no consequence.

7. It is theoretically possible to produce an area of high radiocontamination by overlapping nonsimultaneously arriving fallout. In such a case there would be no beta burns on the hide of animals but deaths would be due to total body irradiation from ground concentrations or the ingested mass. Otherwise, the radiocontamination will be of little consequence to the animal.

8. It is suggested that the limiting factor for survival following a nuclear attack will be man and not the animal. The use of animals and animal byproducts may reduce the hazard of radiocontamination

following nuclear warfare below that which must be tolerated if food is obtained directly from plants. Although total body irradiation and intestinal doses from absorbed isotopes will be much higher for animals, their relative faster maturity and reproductive cycle will compensate.

EFFECT ON FOOD SUPPLIES

The postulated nuclear attack would have very significant effects on the agricultural and food resources in the United States. Those agricultural resources within the range of the immediate effects from blast and thermal radiation would, of course, be vulnerable to destruction. The extent to which fire would be swept by the wind beyond the immediate circular area related to the point of detonation of the weapons was not estimated quantitatively in these hearings. Growing agricultural crops of almost any variety would be expected to be somewhat more vulnerable to the effects of the thermal flash and resultant fire than to the effects of the blast wave.

By contrast, virtually the entire region east of the Mississippi River would be affected to some degree by local fallout resulting from this particular hypothetical attack. The following information was developed in the testimony with respect to the consequences following such deposition:

1. On the mid-October date assumed for the simulated attack, the harvest would have been completed for a number of major agricultural crops, including oats, barley, rye, rice, peaches, winter wheat, tobacco and nearly complete for hay, vegetables, dry beans, and spring wheat. Crops which would be in about the middle of the harvest period include corn, soybeans, apples, pears, grapes, grain sorghum, cotton, and flax. Crops which would not have been harvested include citrus fruits, fall potatoes, sugarcane, and peanuts.

2. The uptake of radioactive isotopes would be most significant for those crops which had not yet been harvested.

3. Iodine 131, iodine 133, and cesium 137 may be readily absorbed directly by leaves and would be the principal isotopes taken up during the early period by plants. Strontium 89 and strontium 90 are absorbed relatively rapidly from the soils and would be taken up at a somewhat slower rate. Other materials such as zinc 65, cerium 144, ruthenium 106, promethium 147, and plutonium 239, are absorbed in amounts ranging generally from one one-thousandth to one-tenth that of strontium 90.

4. The radioactive elements in the heavy local deposits are usually soluble to the extent of 3 percent of the total material, or less. (See sec. VI.) Within the limits determined by the change in solubility as a function of particle size and hence of distance from the point of detonation, the mechanisms of uptake of radioisotopes resulting from fallout deposition in the attack are the same as those described in connection with the mechanisms of uptake of materials derived from the weapon testing program. (See summary report of May hearings.¹⁶)

5. The principal barriers to the recovery of growing agriculture crops would be shortage of fuel and machinery, and radiation hazard to workers. It was the consensus of the testimony that deliberate exposure of workers to radiation in order to save contaminated crops

¹⁶ Fallout From Nuclear Weapons Tests, Summary—Analysis of Hearings, May 5-8, 1950.

would in general not be warranted, unless such food was absolutely essential to survival.

6. The deposition from worldwide fallout would be expected to lead to environmental contamination at a level about 20 times that which has resulted from the weapon-testing program. This level of contamination under the conditions of dire emergency associated with a nuclear attack would not be sufficient to mitigate against the use of such food in the immediate postwar period.

7. Foods which have been harvested could have been subjected to contamination on the outside. If the fallout particles are removed, the food may be considered as essentially "uncontaminated" from the environmental radioactivity viewpoint.

8. Decontamination of land was recommended only for areas having a very high availability of strontium 90, since other isotopes have either short half lives or have a low uptake by plants.

9. In general, if the external gamma radiation level permits the growing, harvesting, and processing of foods, the corresponding threat from radioactivity in food would not impair survival and recovery from the attack.

Testimony regarding the effects on processed and stored foods brought out the following points:

1. Food items stored within a region subjected to blast and thermal damage might be slightly radioactive as the result of activation by neutrons. It would, however, be safe to eat them within a week.

2. There is no significant reduction in the wholesomeness of food subjected to nuclear radiation. This includes effects on vitamins and chemical changes affecting taste and odor.

3. Food containers are, generally, more resistant to blast than are the structures in which they are housed.

4. Processed food, under cover, is not directly affected by fallout. Any deposit on the outside of the container can be easily removed, and with reasonable care in handling the packages, will not get into the food itself. Therefore, processed foods in cans or glass would be the preferred items of diet immediately following a nuclear-attack situation.

LONG TERM ENVIRONMENTAL EFFECTS OF NUCLEAR WAR

One popularly held belief in the public mind is the idea that all-out nuclear war would render a country uninhabitable for many years. For the hypothetical attack considered by the subcommittee the consensus of the testimony on this point indicated that, although the shock could be severe, life would continue and that full ecological recovery would eventually occur.

It was pointed out that immediate effects, particularly from fire, could trigger longtime processes that result in environmental changes of long duration, and therefore changes in the biotic composition of species that could live under the changed conditions. If fire were to denude wide areas of forests and vegetation, the land would become subject to erosion from wind, rain, and snow. New dust bowls might be created.

In areas of severe fallout, unprotected animals, particularly mammals, would sustain severe losses. Whether the areas affected would be extensive enough to significantly affect the natural balance of the

biotic community was not estimated, although the opinion was expressed that if the natural balance among animal species was seriously altered over an extensive area, one of the major postwar problems would be combatting the many insects which are much less subject to radiation effects than mammals.

The consensus of the testimony was that these long-range effects can be considered only in general qualitative terms at the present state of knowledge. This limitation is primarily important to quantitative evaluations of ultimate cost related to a particular attack level, and does not alter the conclusion that survival and recovery are possible after such an attack.

IX. SURVIVAL MEASURES

INTRODUCTION

The assumption of our attack pattern is based on the capability of an enemy to deliver 1,446 megatons of nuclear weapons on U.S. targets, notwithstanding the resistance of our military defensive forces. In such a case the problem of protecting the civilian population goes beyond the preventive power of military defense forces and becomes a responsibility of nonmilitary preparation and organization. This we ordinarily refer to as "passive" or "civil defense."

Our present civil defense activity is based on Public Law 920, 81st Congress, enacted early in 1951, before the development of the hydrogen bomb. The first hydrogen device (preceding actual hydrogen weapons) was exploded in November 1952. This new development in the art brought with it revolutionary problems in military and civilian defense. Public Law 920, geared as it was to the pre-hydrogen weapon age, placed the operating responsibility for civil defense solely on the State and local governmental bodies. Only minor amendments, policywise, have been made since 1951. There has been only a nominal change from sole responsibility of local governments to joint responsibility between the Federal and local governmental bodies. This joint responsibility has not been clearly defined. The estimated casualties from the assumed hypothetical attack are based on the present state of civil defense protection.

It is not the purpose of the subcommittee to pass judgment at this time on the responsibility for planning and funding an effective national civil defense program. The bulk of the testimony was directed toward the development of information which would delineate the effects of a nuclear war on our civilian population and their environment. The problem of survival of civilian populations faced with the threat of nuclear war and the decision as to whether the Federal Government, the State, or the individual pays the bill remains and demands solution.

These facts indicate the path toward the goal of an effective national civil defense program.

The estimates of casualties that might be anticipated as the result of the hypothetical nuclear attack assumed that the preparation of our people was as it stands today, and that a part of the attack was directed against our major centers of industry and transportation. The consensus of expert witnesses was that the major centers of population are more vulnerable to the immediate effects of blast and thermal radiation than to fallout. However, it was also pointed out that

in the event of an attack directed mainly or exclusively against military installations, the resulting fallout would present a serious hazard to densely populated areas hundreds of miles from the targets.

Although the overall problems of national military and civil defense were not within the scope of the hearings, the subcommittee considered that a true picture of the biological and environmental consequences of nuclear war could not be developed without summarizing the technical possibilities dealing with the basic problem of survival for our people.

PROBLEMS RELATED TO A NATIONAL SYSTEM

Protection against fallout is considered the first requirement for protection against the effects of nuclear weapons. It was estimated that about 20 percent of the population would experience fallout levels that would correspond to the condition represented by 3,000 roentgens per hour based on the standard reference time of 1 hour after detonation.¹⁷ From data similar to that presented in section VI, it was shown that this condition would lead to a radiation exposure of about 12,000 roentgens in the first year, and that 10,000 roentgens of this would be encountered in the first 2 weeks.

The basic radiological defense system, derived from the radioactive properties of the fallout material, was proposed to provide three phases:

Phase 1.—Emergency phase where protection from the massive doses of radiation encountered at relatively early times is the major problem. Adequate shelter to provide shielding against the nuclear radiation is considered the only technically feasible answer to this problem.

Phase 2.—Recovery phase when exposure in the open for short times is possible. Advantage is taken of this condition to start reclaiming critical facilities which are necessary for recovery. Removal of the offending debris (decontamination) is considered the most important technical approach when the process of radioactive decay is not sufficient.

Phase 3.—Final recovery to provide for the basic problems of public health and safety when the gamma radiation has decreased to negligible proportions. In the absence of other standards applicable to wartime conditions, a gamma radiation level of 0.3 roentgen per week (the maximum peacetime radiation rate for occupational exposure) was suggested to define this condition. The consensus appeared to be that much larger concentrations of radioisotopes such as strontium 90 and cesium 137 could be tolerated under these conditions than would be considered acceptable in times of peace.

The interrelations between the efficiency of shielding during the emergency phase, the efficiency of decontamination during the recovery phase, and the resultant expected radiation doses absorbed by the population are shown in table IX-1.

¹⁷ This is called the standard intensity.

TABLE IX-1.—*Survival arithmetic*

[Heavy fallout area: 3,000 roentgens per hour at 1 hour]

Shelter shielding factor	Roentgens		
	Emergency dose	Reduction factor	Operational recovery dose
Dose during 1st year.....			12,000
Dose during 1st 2 weeks.....			10,000
Dose between 2 weeks and 1 year.....			2,000
	<i>Roentgens</i>		<i>Roentgens</i>
10.....	1,000	10	200
100.....	100	100	20
1,000.....	10	1,000	2
10,000.....	1		

‡ Emergency phase: 10,000 roentgens.

* Operational recovery phase: 2,000 roentgens.

This table shows that for the fallout condition used—

(1) A shielding factor of 10 is inadequate since a radiation dose of 1,000 roentgens is lethal.¹⁸

(2) A shielding factor of more than 1,000 is not profitable since 10 roentgens is less than 10 percent of the dose required to cause direct casualties. This implies acceptance of the corresponding nonrecoverable biological effects.

(3) A shielding factor of 100 would be adequate if the initial fallout level corresponded to a standard intensity of 300 roentgens per hour at 1 hour instead of 3,000 roentgens per hour at 1 hour.

Different combinations of useful radiological defense systems which relate different combinations of shielding effectiveness, stay time in the shelter, reclamation effectiveness, and radioactive decay properties are summarized in table IX-2.

TABLE IX-2.—*Useful radiological defense systems*

[Heavy fallout area: 3,000 roentgens per hour at 1 hour]

System No.	Emergency phase countermeasures	Operational recovery phase countermeasures	Dose during 1st year (roentgens)
1	6-month shelter with 0.01 residual number.....	None.....	320
2	6-month shelter with 0.001 residual number.....	None.....	210
3	2-week shelter with 0.01 residual number.....	0.1 reclamation.....	300
4	2-week shelter with 0.001 residual number.....	do.....	210
5	2-week shelter with 0.01 residual number.....	0.01 reclamation.....	120
6	2-week shelter with 0.001 residual number.....	do.....	30

Other factors relating to a national system may be summarized as follows:

(1) The need for a formal radiological defense system disappears at fallout levels less than a standard intensity of 100 roentgens per hour at 1 hour. The protection afforded by existing buildings is generally adequate for this condition.

(2) Most buildings offering a shielding factor of 100 or more are located in metropolitan centers and will be vulnerable to the effects of blast and fire if that area is a target.

¹⁸ A shielding factor of 10 is provided in the basement of some two-story homes. See "The Effects of Nuclear Weapons," p. 404. The corresponding residual number which relates the dose in the unprotected condition to the dose with the countermeasure is 0.1.

(3) Where such protection does exist, additional provisions for ventilation, food and sanitation would have to be made.

(4) Very good protection can be provided by underground shelters. The best information available is for a particular design based on a 24- by 48-foot ammunition-storage magazine¹⁹ buried under 3 feet of earth. This shelter was occupied by technical personnel at Operation PLUMBOB²⁰ at a distance of somewhat less than 1 mile from a 17-kiloton detonation. A documentary film shown at the hearings gave an impressive demonstration of its effectiveness.

(5) The USNRDL shelter provides for 100 people at an estimated cost of \$100 to \$125 per person sheltered. It provides a shielding factor for radiation of 1,000 or more, and protection against blast at a level of 10 pounds per square inch. Protection against mass fires can also be provided.

(6) The USNRDL shelter can be designed for protection against a blast pressure of 35 pounds per square inch. Availability of such protection under conditions of the subcommittee's hypothetical attack could reduce the fatalities from approximately 25 percent of the U.S. population to about 3 percent. All of these would result from the immediate blast effects—no deaths from either thermal or nuclear radiation being anticipated under these conditions.

(7) The cost of providing protection for 200 million people at the levels prescribed by the higher performance defense system was estimated as between \$5 billion and \$20 billion, depending on the use made of existing facilities. This cost is almost entirely in the shelter phase, since reclamation competence is largely a matter of training and organization.

(8) The main conclusion presented to the subcommittee was that the country must have a national radiological defense system if the Nation is to withstand and recover from an attack of the scale which is possible in an all-out nuclear war.

In addition to data on group-type shelters, the subcommittee also received testimony on techniques of adapting present buildings for shelter purposes and proposals for individual family shelters.

Information bearing on these points may be summarized as follows:

(1) Techniques for estimating the degree of protection that can be obtained from existing buildings have recently been developed.

(2) On the first floor of a two-story wood building, the radiation was estimated to average about one-half of that outside. On the first floor of a brick building, it was one-seventh.

(3) Closing openings in basements with bricks or sandbags will reduce the radiation in the basement by a significant amount.

(4) Radiation dose rates inside fireplaces and behind masonry chimneys are lower than those in the center of the room.

(5) A heavy table covered with 7½ inches of concrete block and placed in the corner of a basement will reduce the radiation dose rate by a factor of 200 to 1,000 over that observed on the ground outside the structure.

(6) Prototype models of a combination transistorized portable radio and radiation detection unit were demonstrated at the hearings. This concept of a "citizen's instrument" is known as the "Banshee" because

¹⁹ This is basically a prefabricated building of the type known as a quonset hut.

²⁰ This test was conducted by the U.S. Naval Radiological Defense Laboratory under the sponsorship of the Atomic Energy Commission.

the output from the radiation-detection unit is converted to a wailing signal which is amplified through the loudspeaker of the radio. Such a device when the radio is operating, gives clear warning of the presence of significant amounts of fallout.

(7) A new pamphlet has been issued by the OCDM which gives complete specifications for an individual family fallout shelter.

A considerable body of civil defense information has been developed by the Department of Defense, the Office of Civil and Defense Mobilization, and the Atomic Energy Commission. Shelter-design studies and evaluation tests have been conducted, decontamination and fallout monitoring techniques and equipment have been developed, and studies of weapons effects and various aspects of fallout have been undertaken.

In addition, the OCDM has conducted numerous exercises, including its annual Operation Alert, to determine the effectiveness of civil defense doctrine and operations under hypothetical attack conditions.

All of the data developed by these agencies is available for use in formulating a national civil defense program of the type suggested in the testimony presented at the subcommittee hearing. The present study, as well as other congressional investigations, such as those conducted by the Military Operations Subcommittee of the House Committee on Government Operations indicate the need for an improved and more effective national program of civil defense.

ADDENDUM

A DIGEST OF TESTIMONY ON STRATEGIC CONSIDERATIONS

INTRODUCTION

The discussion of survival measures in the body of this report related to the technical aspects of achieving various degrees of protection from the effects of nuclear weapons. The subcommittee's purpose in soliciting expert testimony on that subject was to provide an up-to-date public record of available data which are believed to be pertinent to a full consideration of the effects of a possible nuclear war. The subcommittee did not undertake to establish a case for or against any particular plan of protection or specific civil defense measures. Such an undertaking was not within the scope of the subcommittee's inquiry.

By the same token, the subcommittee did not endeavor to examine current national security and foreign policy with a view to formulating alternatives or recommending changes in existing policy. However, the data presented to the subcommittee with respect to the immediate and protracted effects of nuclear weapons may have far-reaching strategic implications deserving most careful consideration by the executive branch and the Congress.

For this reason, the subcommittee presents in the pages which follow a digest of testimony concerning the major strategic implications arising from the basic calculations presented at the hearings. Mr. Herman Kahn of the Center of International Studies, Princeton University, made the main presentation on this subject and was followed by a review panel of other principal witnesses.¹

"BALANCE OF TERROR" CONCEPT

The subcommittee was told that recent calculations tend to cast doubt particularly on the widely held notion that nuclear weapons have created a "balance of terror." This theory holds that a thermonuclear war would mean the certain and automatic annihilation of both the antagonists and that it might possibly mean the end of civilization. To some, this concept of a "balance of terror" means that wars will be avoided, if it is assumed that no sane man would initiate a war in which there could be no victor. Thus, it is said, the very violence of nuclear weapons will eliminate war from the world entirely.

There are also other major implications of this theory. If both sides can utterly destroy the other, preparations to reduce casualties and lessen damage will be of no avail and there is no need to shoulder the financial burden of such preparations. Some people have carried

¹ It may be noted, incidentally, that Mr. Kahn testified that the calculation of effects presented to the subcommittee were very similar to those made by Mr. Kahn and his associates at the Rand Corp. 2 years earlier, though they were made independently and without reference to the data developed by the Rand Corp.

this argument even further. They have agreed that modern weapons are so enormously destructive that a very few of them would suffice to deter the enemy and that it is therefore possible to deter war with much smaller deterrent forces than we have provided in the past.

A very similar debate apparently took place in the Soviet Union several years ago. One witness testified that in 1955-56 Malenkov agreed that nuclear war would mean the end of civilization, the Soviet Union could afford to reduce both their investment in heavy industry and their military expenditures and concentrate on consumers' goods. Khrushchev and the Soviet military took the opposite position and in general their view seems to have prevailed.

The subcommittee was told that although thermonuclear war would be horrible in the extreme it would not necessarily mean the total destruction of both sides and that the "balance of terror" theory may be in error. In terms of immediate casualties in the United States, specialists testified that in the hypothetical attack specified, about 30 percent of the American population would be killed. This assumed only very primitive measures to protect the general population and, although there was no attempt to examine what would have happened if, for example, the attack had come after a period of international tension providing time for people to get out of target areas or if adequate shelter protection had been provided, the testimony indicated that to the extent that advance measures had been taken the casualties would have been greatly reduced. It was stated that studies by the Rand Corp. have indicated that with certain advance measures, the United States might well be able to recover almost completely from such a disaster in about 10 years.

It was stated that although the long-term genetic effects of radioactive fallout would be severe, these effects would be spread out over hundreds of years. Even though the total is large, the percentage of people affected in any one generation would be small and it is doubtful if the possibility of damage to 1 or 2 percent of future generations of his own population could by itself operate as a deterrent to a determined enemy.

THE FIRST-STRIKE ADVANTAGE

It was indicated that the degree of damage one side or the other suffers will depend very much upon the circumstances in which the war occurs. The attacker has enormous advantages. He chooses the time and method of attack, presumably exploiting any possible weaknesses in the other's defense. The defender must strike back *with a damaged force*, piecemeal and without coordination, in the teeth of a *fully alerted air defense system*, and against *an enemy population that has taken at least minimum precautions*. Without considering classified information, it is very difficult to estimate how much damage the attacker would suffer, but some of the testimony indicated that it would be significantly less than that estimated for the damage on the United States in the hypothetical attack considered.

The conclusion submitted to the subcommittee by one witness was that the United States cannot rely on an automatic "balance of terror" that could be maintained by minimum retaliatory forces with no protection provided for the civilian population. Adequate deterrence, it was said, can be maintained only by providing, first, a

force that can absorb an enemy blow and still strike back with adequate strength and, second, certain minimum nonmilitary protection for the civilian population.

TYPES OF DETERRENCE

It was also stated that even if the "balance of terror" theory were correct, the United States would still be faced with important strategic problems. As the witness pointed out, in 1914 and 1939, it was the British and the French who declared war on the Germans and not vice versa. It is difficult for Americans to realize that, under certain circumstances, neither the Soviets nor the Europeans might believe that the United States would come to the aid of Europe. In making this point, the witness asked the subcommittee to ponder a hypothetical situation in which American defenses were so weak and Soviet retaliatory forces so strong that if the United States responded to a Soviet ground attack on Europe the Soviet counter-retaliation would kill all 177 million Americans. Under such conditions, the witness said, it would not be surprising if neither the Europeans nor the Soviets found the U.S. promise to come to the aid of Europe credible. But if it is true that the Soviets and the Europeans would not believe that we would honor our commitments to our allies if it meant 177 million American deaths, what level of casualties do they believe we would accept? It was stated that, to the extent that the Soviets believe we can keep our casualties to a level we would find acceptable, whatever that level may be, they will be deterred not only from attacking the United States directly, but also from very provocative aggressions, such as a ground attack on Europe. But, it was said, to the extent that they do not believe we can keep casualties to an acceptable level, the Soviets may feel safe in undertaking these extremely provocative military adventures.

In discussing this aspect of the strategic problem facing the United States, the witness distinguished between what he called Type I deterrence and Type II deterrence. Type I deterrence, which the British call "passive deterrence" on the assumption that it requires no act of will to initiate a response, is the deterrence of a direct attack. If the United States were directly attacked, its response would be automatic. Type II deterrence, which the British have called "active deterrence" is defined as the forces necessary to deter an enemy from engaging in military adventures short of a direct attack on the United States itself. There is a question as to how effective nuclear retaliatory forces would be as a Type II, "active" deterrent. In pondering this question, it must be assumed that before launching on such an extremely provocative adventure, the enemy would have alerted his own retaliatory forces and instituted protective measures for his population. By such precautionary measures, the Soviets, according to the witness, might limit casualties to 10 percent of its population and one-third of its wealth. This is just about what they suffered in World War II, from which they had recovered by 1951. If the Soviets believed that they could limit destruction to this extent and were also convinced that the United States had failed to take the measures that would similarly limit destruction in the United States, they might well feel free to launch an aggressive attack.

RELATIVE VULNERABILITY OF THE UNITED STATES AND THE SOVIET UNION

There was no testimony to indicate that U.S. defenses were so weak or Soviet forces so strong that the hypothetical situation described above would soon become a reality. On the other hand, one witness testified that if the current rates of Soviet and American progress in long-range delivery systems continues relatively the same, and if current American air and civil defense programs remain basically unchanged, a situation might well arise in the future in which neither the U.S. Type I or Type II deterrence would be effective.

A clear advantage was attributed to the Soviet Union with respect to relative vulnerability to the effects of a possible nuclear war. The Soviet Union, for example, has only 50 million people in its 135 largest cities, while 42 million Americans are concentrated in our 12 largest metropolitan areas, with 12 million in the New York metropolitan area alone.

The testimony indicated that, given the aggressor's advantage of forewarning, it is not inconceivable that the Soviet Union could achieve an 80 percent evacuation of its target areas, leaving only 10 million persons in concentrated target cities. Moreover, it was stated that recent studies of Soviet civil defense indicate that a substantial program was recently instituted to train the entire Soviet population in basic survival techniques. However, it is understood that prior to 1958 the Soviet program was not geared to thermonuclear weapons.²

In the United States the situation is vastly different, as a number of witnesses pointed out. In contrast to the Russian people, Americans are almost totally unfamiliar with what would be required of them under conditions of a possible nuclear war. There is no experience, such as the Soviet people have undergone, of having risen from the ruins of wartime destruction to a pinnacle of postwar power. Finally, of course, there is no comprehensive program for protecting the American people in the event of a nuclear war, a program which, as Dr. Libby said, should "tell the people what they may be up against" and what must be done.

Various witnesses indicated that this is a lack which can prove very dangerous for the success of American and western policy against Communist aggression. For it is apparent from the testimony of these hearings that the total unreadiness of the American people to survive a nuclear war—a state said to be well known both to the Russians and to our allies—can greatly undermine our capability to resist possible Soviet "nuclear blackmail." As the subcommittee was told:

The possibility that if you cannot accept the Russian retaliatory blows, and it is clear to the Russians and the Europeans and you that you cannot accept it, you may be in a very, very sad position. * * *

But the testimony indicated that it is not too late to take measures to correct this weakness. As already indicated in the preceding section of this report, fallout protection would have saved the approximately 22 million radiation casualties resulting from the hypothetical attack on the United States.

² "Civil Defense in Western Europe and the Soviet Union," report of the Military Operations Subcommittee of the House Committee on Government Operations, H. Rept. No. 300, 86th Cong., 1st sess., April 1959.

Put another way, the subcommittee was told, a very moderate shelter program, which would combine protection against fallout and some blast resistance, could reduce the expected casualties to approximately one-third of those who would die if there were no protection at all. A more extensive program, designed to protect persons in our urban areas, could reduce the overall fatalities of this attack from 25 percent of the population to approximately 3 percent.

Such measures were believed not to be terribly expensive. The subcommittee was told that the program of fallout shelters, which would go far toward saving the lives of the 60 percent of all Americans who do not live in or near target areas, is one which depends on simple tools and simple techniques. The lives of millions could be saved or lost by a simple choice. Thus, one eminent witness pointed out that on the basis of the 1954 thermonuclear detonation at Bikini, where the area of blast and thermal effects was perhaps 300 square miles (a circle with a radius of $9\frac{1}{2}$ miles), the total area of likely radiation casualties was approximately 7,000 square miles. Clearly, the subcommittee was told, it is the people in the intermediate 6,700 square miles about whom something could be done: "We can save them easily; we can lose them easily."

The burden of the testimony received on this point was that if such protective measures were taken, the impact of America's ability to survive a nuclear war would be so great that the likelihood of such a war would be vastly reduced. So long as the Soviets have the advantage of forewarning and can reduce their already low vulnerability through a comprehensive civil defense program, the United States will be at a marked disadvantage. Its firm foreign policy will be open to doubt and disbelief, and to possible blackmail.

Thus, it was suggested that our lack of a civil defense program could lead the Soviets to take a provocative step which we could not ignore, and a nuclear war would have started with no protection for the American people. Or, as a final paradox, the subcommittee was told, in a world of great tension the Soviets may be unable to believe that we would allow an aggressor to strike us first, which the theory of "massive retaliation" implies. The acceptance of such a military disadvantage as a basis for our national policy may seem foolish to them. They may therefore discount the sincerity of our position and expect instead that the United States actually intends to strike the first blow. A war which neither side wanted could thus break out because of our defensive weakness.

APPENDIX

GLOSSARY OF TERMS

Alpha particle.....	A fundamental particle resulting from radioactive decay, consisting of 2 protons and 2 neutrons and possessing kinetic energy or energy of motion. The energy of an alpha particle is measured in million electron volts. Abbreviated: Alpha.
Average or mean life.....	The actual life of any particular radioactive atom, can have any value between zero and infinity. The average or mean life of a large number of atoms, however, is a definite quantity and is equal to 1.44 times the half life.
Beta particle.....	A fundamental particle resulting from radioactive decay. It consists of a negatively charged electron possessing kinetic energy or energy of motion. Beta particle energies range from kilo electron volts to million electron volts. Abbreviated: Beta.
Biological half life.....	The biological half life of any element or radioactive nuclide is the time interval required to reduce the number of atoms present in the body to half of their initial value. The biological half life does not include the radioactive half life of a radioactive element.
Curie.....	That quantity of a radioactive nuclide disintegrating at the rate of 3.70 by 10^{10} atoms per second or 2.22 by 10^{12} atoms per minute. Abbreviated: c.
Micromicrocurie.....	1 million millionth of a curie or that quantity of a radioactive nuclide disintegrating at the rate of 3.7 by 10^{-3} atoms per second or 2.22 atom per minute. Abbreviated: $\mu\mu\text{c}$.
Millicurie.....	1 thousandth of a curie or the quantity of a radioactive nuclide disintegrating at the rate of 3.70×10^7 atoms per second or 2.22×10^9 atoms per minute. Abbreviated: Mc.
Megacurie.....	1 million curies or the quantity of a radioactive nuclide disintegrating at the rate of 3.70×10^{16} atoms per second or 2.22×10^{18} atoms per minute. Abbreviated: Mc.
Dose.....	The radiation delivered to a specified area or volume or to the whole body.
Effective half line.....	The time required for a radioactive element in the body to be diminished to half of its value as a result of the combined action of radioactive decay and biological elimination.

Electron volt.....	A unit of energy equivalent to the amount of energy gained by an electron in passing through a potential difference of 1 volt. Larger multiples of the electron volt are frequently used, viz, Kev. for thousand or kilo electron volts; Mev. for million electron volts; and Bev. for billion electron volts.
Erg.....	Unit of work or energy done by a unit force acting through unit distance. The nuclear unit of work or energy is the Mev. which is equal to 1.6×10^{-6} ergs.
Gamma ray.....	Electromagnetic radiation resulting from radioactive decay. Gamma rays have no mass and no charge, but have energy which ranges from Kev. to Mev.
Half life.....	The half life of a radioactive atom is the time interval over which the chance of survival is exactly one-half. In any large number of disintegrating radioactive atoms half of the atoms present at any time will decay during one-half life. The half life for a particular nuclide is given by $t_{1/2} = \frac{0.693}{\lambda}$ where λ is a constant for each nuclide.
Biological half life.....	The biological half life of any element or radioactive nuclide is the time interval required to reduce the number of atoms present in the body to half of their initial value. The biological half life does not include the radioactive half life of a radioactive element.
Effective half life.....	The time required for a radioactive element in the body to be diminished to half of its value as a result of the combined action of radioactive decay and biological elimination.
Radioactive half life.....	The half life of a radioactive atom is the time interval over which the chance of survival is exactly one-half. In any large number of disintegrating radioactive atoms half of the atoms present at any time will decay during one-half life. The half life for a particular nuclide is given by $t_{1/2} = \frac{0.693}{\lambda}$ where λ is a constant for each nuclide.
Stratospheric half life.....	The time interval required to reduce the activity present in the stratosphere to half by removal from the stratosphere to the troposphere. Stratospheric half life does not include radioactive half life of any of the radioactive nuclides.
Isotope.....	An isotope is the individual species of atoms in an element having a certain mass. For example: U^{235} , U^{238} , and U^{233} are isotopes of uranium.
Kilo electron volt.....	See electron volt.

Mean or average life.....	The actual life of any particular radioactive atom can have any value between zero and infinity. The mean or average life of a large number of atoms, however, is a definite quantity and is equal to 1.44 times the half life.
Megacurie.....	1 million curies or the quantity of a radioactive nuclide disintegrating at the rate of 3.70×10^{18} atoms per second or 2.22×10^{18} atoms per minute. Abbreviated: Mc.
Micromicrocurie.....	1 million millionth of a curie or that quantity of a radioactive nuclide disintegrating at the rate of 3.7×10^{-3} atoms per second or 2.22 atoms per minute. Abbreviated: $\mu\mu c$.
Millicurie.....	1 thousandth of a curie or the quantity of a radioactive nuclide disintegrating at the rate of 3.70×10^6 atoms per second or 2.22×10^6 atoms per minute. Abbreviated: Mc.
Million electron volts.....	See electron volt.
Nuclide.....	A nuclide is the individual species of atoms in an element having a certain mass and a specific energy content. Therefore, more than 1 nuclide may compose an isotope. For example, Ba-137m (radioactive) and Ba-137 (stable) are nuclides of the same isotope.
Rad.....	The unit of absorbed dose, which is 100 ergs per gram. The rad is a measure of the energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest. It is a unit that was recommended and adapted by the International Commission on Radiological Units at the Seventh International Congress of Radiology, Copenhagen, 1953.
Relative biological effectiveness.....	The ratio of gamma or X-ray dose to the dose that is required to produce the same biological effect by the radiation in question.
REM.....	Roentgen equivalent man: that quantity of any type ionizing radiation which when absorbed by man produces an effect equivalent to the absorption by man of 1 roentgen of X- or gamma radiation (400 KV).
REP.....	Roentgen equivalent physical: the amount of ionizing radiation which will result in the absorption in tissue of 83 ergs per gram. (Recent authors have suggested the value of 93 ergs per gram.)
Stratosphere.....	The upper portion of the atmosphere, above (11 km), more or less (depending on latitude, season, and weather) in which temperature changes but little with altitude and clouds of water never form, and in which there is practically no convection.
Stratospheric half life.....	The time interval required to reduce the activity present in the stratosphere to half by removal from the stratosphere to the troposphere. Stratospheric half life does not include radioactive half life of any of the radioactive nuclides.

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- Strontium unit**----- Formerly sunshine unit. 1 thousandth of the maximum permissible body level of Sr-90. It is equal to 1 micromicrocurie per gram of calcium.
- Tropopause**----- The imaginary boundary layer dividing the upper part of atmosphere, the stratosphere, from the lower part, the troposphere. The tropopause normally occurs at something like 35,000 to 55,000 feet altitude, although it depends on season and location.
- Troposphere**----- All that portion of the atmosphere below the stratosphere. It is that portion in which temperature generally rapidly decreases with altitude, clouds form, and convection is active.

